This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

UC-NRLF
$B 259 095

YA 01167

Electr

REESE LIBRARY
OF THE
UNIVERSITY OF CALIFORNIA
Received Aug. 1887
Accessions No. 34666 Shelf No.

H. SOTHERAN & CO

20

FRICTIONAL ELECTRICITY

BY

THOMAS P. TREGLOHAN

HEAD MASTER

ST JAMES'S SCIENCE AND ART SCHOOLS, KEYHAM, DEVONPORT

REESE LIBRARY
OF THE
UNIVERSITY

LONDON
LONGMANS, GREEN, AND CO.
1886

T7

PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
LONDON

34666

PREFACE.

THE present volume has been prepared with the same idea as the 'Text-Book of Magnetism,' to meet the syllabus of the Science and Art Department for the Elementary Stage, and to satisfy the requirements of the second stage of one of the Physics Courses of the 'Mundella Code,' as laid down by the Education Department.

The same plan is followed in this work as in the 'Magnetism,' viz., thorough explanation, clear diagrams, and numerous experiments to illustrate every phase of the subject. The experiments are adapted for the teacher's use in illustrating his lectures, or for the pupil's private practice for his own special benefit.

The diagrams should be carefully drawn, and every division of the subject thoroughly mastered.

All the questions which have been set in the Elementary Stage since 1867 are collected at the end of the book, and numbers are attached referring to the page of the work where the explanations may be found.

A supplementary chapter has been added on 'Suggestions as to Apparatus,' and the author trusts this may be found useful to many students.

The author is indebted to other writers on electricity in one or two instances for short extracts and diagrams.

T. P. T.

St. James's Science and Art Schools,
Keyham, Devonport: *June*, 1885.

SYLLABUS OF SCIENCE AND ART DEPARTMENT.

SUBJECT IX. PART II.

First Stage, or Elementary Course.

FRICTIONAL ELECTRICITY.

Electrification by friction. Two distinct electrical states and their mutual relations. Positive and negative electrification. Simultaneous and equal development of the two electrical states. Action of electrified bodies on each other. Conductors and non-conductors. Effect of connecting a conductor. Experiments illustrating the relation between a primary electrical charge and the correlative induced charge. The Leyden jar and similar arrangements. Distribution of electricity on conductors. Action of points. Properties of hollow conductors. Frictional electrical machines. Electric discharge.

SYLLABUS FOR ELEMENTARY SCHOOLS.

New Code, 1882.

PHYSICS.

STAGE II.—ELECTRICITY (FRICTIONAL).

Attraction of light bodies by rubbed sealing-wax and glass.
Experimental proof that there are two forms of electricity.
Attraction and repulsion.
Gold leaf electroscope.
Construction of electrophorus, electrical machine and Leyden jar.
Explanation of atmospheric electricity.

CONTENTS.

INTRODUCTORY REMARKS.

First reference to Electricity—Dr. Gilbert's investigations—Volta's discovery—Further development—Necessity for experiment—Tyndall's opinion—Guthrie's opinion . . . . . pages 1–3

1. Electrification by Friction.

Result of rubbing two bodies together—Attraction of light bodies—*Experiments*—Influence of moisture on the charging of bodies—Glass and sealing-wax representative substances—Supports for glass and sealing-wax rods—The Electric Pendulum—*Experiments* . . . . pp. 3–7

2. Two Distinct Electrical States and their Mutual Relation.

Vitreous Electricity—Resinous Electricity—Positive and negative—*Experiments*—Theories of Electricity—One-fluid theory—Two-fluid theory—Numerical representation of two-fluid theory—Numerical representation of one-fluid theory . . . . . pp. 7–12

3. Positive and Negative Electrification.

Electricities of glass and sealing-wax rods examined—Action on charged pith ball—*Experiments* . . . . . pp. 12–14

4. Simultaneous and Equal Development of the two Electrical States.

One kind cannot be excited without the other—Electroscopes—The Electric Pendulum—The Pith-ball Electroscope—The Gold-leaf Electroscope—The Proof Plane—Carrier Ball—Use of electroscope—Method of charging: (*a*) positively, (*b*) negatively—*Experiments*—Equal quantities in rod and rubber—Faraday's experiment—*Experiments* . . . . pp. 14–23

5. Action of Electrified Bodies on each other.

Charged rods on neutral pith ball—Charged pith balls on each other—Strips of silk ribbon, and ribbons of gutta-percha electrified—Electrical laws—*Experiments* . . . . pp. 23–25

6. Conductors and Non-conductors.

Conductors—Non-conductors—Semi-conductors—Lists of each—Non-electrics and electrics—Brass rod held in hand or by insulating handle—Insulating Stool—Human body earth-connected or insulated—Method of testing conductors and non-conductors—Conductors and insulators — Conductivity of wire and silk string contrasted — Wet string — Insulation — Conduction — *Experiments* . . . . pp. 25–32

7. Effect of connecting a Conductor with the Earth.

Conductors in earth-connection and insulated—Result of touching conductor under inductive action of rod—Method of charging conductor—Induction — Free Electricity — Bound Electricity — Specific inductive capacity—*Experiments* . . . . . pp. 32–36

8. Experiments illustrating the relation between the Primary Electrical Charge and the Correlatively Induced Charge.

Successive steps of inductive action—On neutral pith ball—Gold-leaf electroscope—Faraday's Ice-pail experiments—Action on conductors—Two insulated balls—Charged conductors on each other—The Electrophorus—Description — Method of charging — Continuous charge—*Experiments* . . . . pp. 36–46

9. Frictional Electrical Machines.

Kinds of frictional machines—Cylinder machine—Description—Charging machine—Positively—Limit of charge—Negatively—Methods of showing tension—Henley's Quadrant Electrometer—Use—Plate machine—Ebonite or metal plate—Method of charging plate machine—Winter's machine—Theories of charging prime conductor—*Experiments* . . . . pp. 46–58

10. The Leyden Jar and similar arrangements.

Condensation of electricity—Condenser explained—Three forms of condensers—Epinus's—Method of charging—Disruptive and spontaneous discharges—Discharge—Slow—Instantaneous—Discharging rod—Explanation of discharge—Discharge through human body—Strength of charge—Highest specific inductive capacity—Franklin's Pane—Charging and discharging—*Experiments*—Leyden Jar—History—Description—How charged—Positively—Negatively—Effect of insulating jar—Connecting inner and outer coating with earth—Discharge—Slowly—Instantaneously—Residual charge—Where electricity is stored—Jar with movable coatings—Charging and discharging—Leyden Batteries—Ordinary form—Charging and discharging—Universal Discharger—Effects of discharge—Cascade arrangement—Charging and discharging—*Experiments*—Unit Jar—Use—Harris's—Lane's Electrometer—Condensing Electroscope—*Experiments*. . . . . pp. 59–84

11. Distribution of Electricity.

Charge on outside of conductor—Methods of testing—Distribution on sphere—Cylinder—Ellipsoid—Disc—Cube—Density where greatest—Quantity, area, density, tension—Subdivision of charge—Equal spheres—Unequal spheres—Relation between area and density—Electrical tension . . . . pp. 84–89

12. Distribution on Hollow Conductors.

Same on solid or hollow balls—Biot's experiment—Hollow conductor tested with proof plane—Faraday's Butterfly Net—Cubical room—Electroscopes protected—Illustration of distribution—Exceptions to general law—*Experiments* . . . . . . pp. 89–95

13. Action of Points.

Points attached to and presented towards charged bodies—Tension of prime conductors reduced—Electrical aura—Use when attached to prime conductor and rubber—Action of needle on charged rod—Action of point in conductor either turned towards or away from a charged body—Point projecting from pith ball—Electrical whirl—Electrical inclined plane—*Experiments* . . . pp. 95–99

14. Electrical Discharges.

Three forms of spark—Luminous effects—Spark and glow discharges—St. Elmo's Fire—Illuminated designs—Leyden Jar—Luminous Leyden Jar—Electric Egg—Geissler's Tubes—Chemical effects—Volta's Pistol—Ozone—Heating effects—Liquids ignited—Gas lit—Platinum wire heated—Gunpowder and gun-cotton exploded—Mechanical effects—Card punctured—Glass and wood—Leyden Jar pierced—Magnetic effects—Needles or strips—Action on Galvanometer—Physiological effects—Effect from prime conductor—Leyden Jar—Leyden Battery—Tyndall's remarks—Lichtenberg's figures—Effect of heat—White-hot iron ball—Bright-red—Dull-red—Action of flames—Evaporation—Induced currents—Use of flat spirals—Secondary and tertiary currents—Duration of spark—Velocity of Electricity—Illustrations of velocity—*Experiments* . . . . pp. 99–112

15. Electrometers.

Use—Simplest forms—Chief electrometers—Coulomb's Torsion Balance and experiment—Peltier Electrometer—Sir Wm. Thompson's Quadrant Electrometer—*Experiments* . . pp. 112–115

16. Atmospheric Electricity.

Electricity of air—Lightning and thunder—Thunderstorm and fulminating pane—Kinds of Lightning—Thunder—Crash and peal—Distance of discharge—Return shock—Lightning-conductors—Use—Area of security—*Experiments* . . . . pp. 115–121

17. Suggestions as to Apparatus for Frictional Electricity.
pp. 121–125

18. Brief History of the development of Frictional Electricity.
pp. 125–127

Questions in Frictional Electricity which have been set by the Science and Art Department from 1867 to 1885, and references to the pages of the work where the Answers may be found . pp. 128–135

REESE LIBRARY
OF THE
UNIVERSITY
CALIFORNIA.

TEXT-BOOK

OF

FRICTIONAL ELECTRICITY.

THE development of this branch of physics has been the result of the careful observation of simple experiments by scientific minds during the last three centuries.

Until the reign of Queen Elizabeth, A.D. 1600, little was known of Frictional Electricity beyond the fact that, when *amber* was rubbed, it attracted light bodies, so as to cause them to stick to it. This was first mentioned about 600 B.C. by the Greek philosopher Thales, and is considered to be that from which electricity derived its name; for the Greek word for amber is *elektron*, in which we can see the resemblance to the word now used. After an interval of more than 2,000 years, Dr. Gilbert, an eminent scientist and physician to Queen Elizabeth, gave the science a fresh impulse by his experiments with glass, resin, spars, gems, &c.

He proved that these substances, when rubbed, exhibited similar effects to those which amber did. From these investigations the science has been gradually and successfully unfolded by a long list of thoughtful experimenters, each adding some new principle which he had successfully investigated, or laying down some new law which he had conclusively established.

From an accidental occurrence in 1790 A.D., and the reflections of Volta connected therewith, Electricity was studied as the result of chemical action on dissimilar metals, which were placed in liquids, and connected in circuit. This was the dawn of current, or as it is known from its first investigator, Voltaic Electricity, which for some time made steady progress; but within the last few years has taken marvellous strides, giving us the electric telegraph, electric engines, electric light, electric railways, &c.

What it is destined to accomplish for mankind in the subsequent history of the world is a problem, which the most penetrating intellect cannot presume to predict. It is without doubt one of the most mighty forms of energy, and, as time rolls on, will no doubt be still more wonderfully developed.

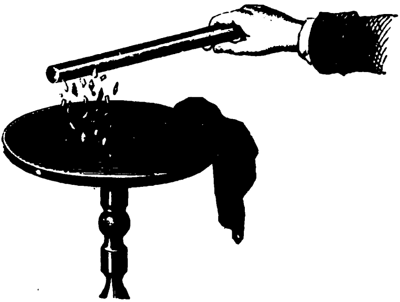
It should be the object of everyone studying this subject to test every phase of it by as many experiments as possible, that the mind may be familiarised with the simple phenomena, which have led to marvellous discoveries. Professor Tyndall, in his work on Electricity, writes concerning the *art of experimenting*: 'It is an art of extreme importance, for by its means we can, as it were, converse with nature, asking her questions and receiving from her replies. In this way you will come into direct contact with natural truth—you will think and reason not on what has been said to you in books, but on what has been said to you by Nature. Thought springing from this source has a vitality not derivable from mere book-knowledge.'

Professor Guthrie, the examiner in Sound, Light, and Heat, and Magnetism and Electricity, says in his report on the Examination of Training Colleges in the annual report of 1882: 'In many cases the teaching appears to have been mainly theoretical. Many of the answers show that the examiner, while understanding the conventional description of a piece of apparatus, has probably never seen it, and certainly never used it. This won't do; and for a very small sum many bits of apparatus may be purchased or made, and where this subject is taught the teacher should allow the pupils to try the experiments for themselves, that they may gain confidence, and he might inform them of the best means of obtaining or making little things for their own use. I therefore venture to point out that for training colleges sufficient laboratories are necessary. No description, however conscientious, can take the place of seeing, handling, and using physical apparatus.'

1. Electrification by Friction.

By Friction is meant the rubbing of one body against another body. When this takes place electricity is produced on the bodies rubbed together, and under certain conditions it may be accumulated, so that its presence may be perceived by its influence on other neutral or electrified bodies. To exhibit this we must resort to experiment.

FIG. 1.



Excited Rod attracting light bodies.

A body in which electricity is apparent is said to be *excited*, *charged*, or *electrified*, and it will then attract light bodies, such as bran, small bits of paper, small bits of pith, bits of gold leaf, and other very light substances (fig. 1). As previously mentioned, amber was the first substance tested, but afterwards glass, sealing-wax, resin, gutta-percha, ebonite, vulcanite, gems, and spars were similarly examined.

Experiments.—Take piece of amber, glass rod, ebonite rod, stick of sealing-wax, stick of sulphur, and sheet of coarse brown paper, and rubbers of silk, fur, and flannel. Excite amber with flannel, glass with silk, ebonite with fur, sealing-wax and sulphur with flannel, brown paper with fur or coat-sleeve. Test each excited body by holding them in succession just above such light bodies as those mentioned, and

Google

certain effects will result. In some cases the light bodies, particularly if they have points about them, will be attracted to the electrified body, and will stick to it. In other cases, as in the tiny pith-balls, there will be attraction and repulsion, frequently repeated, causing them to jump to and be driven from the excited body.

Note.—It should be stated at the outset that the moisture in the atmosphere has a very bad effect upon experiments in Frictional Electricity; and, even with the greatest care, it sometimes prevents an experiment being successfully performed. To counteract this deposit of moisture on the bodies to be excited they must be slightly warmed, and the rubbers well dried. Great care is required with glass rods, as they are more liable to this dewy deposit than the other substances mentioned. Brown paper is best excited, when it is heated until it just begins to smoke, and then smartly rubbed.

Two of these substances, *glass* and *sealing-wax*, soon became selected as *representative substances*, the former when it was rubbed with silk, and the latter when rubbed with flannel; for it was found that the electricity developed on glass and sealing-wax under these conditions exhibited opposite effects on similarly excited substances when they were brought within the influence of one another. For example, glass rubbed with silk repelled glass rubbed with silk, but attracted sealing-wax rubbed with flannel; while sealing-wax rubbed with flannel repelled sealing-wax rubbed with flannel, but attracted glass rubbed with silk.

In order that such experiments may be performed, the glass, or sealing-wax, must be supported so as to be exactly balanced, that it may be able easily to move horizontally. This may be done by closing the ends of the tube in a blow-pipe flame, finding the middle of the tube by balancing it on a knife-blade or other equally sharp edge, heating this spot in a blow-pipe flame, and making a slight depression while the glass is soft, with a compass leg or other sharp-pointed instrument.

To support it a stand may be made, consisting of a block of wood 3 in. square, having a hole in the centre into which a piece of glass tubing 6 in. long and $\frac{1}{4}$ in. in diameter is placed. The upper end of the tubing should be filled with shell-lac for about $\frac{1}{2}$ in., and then the hot eye of a needle pushed into the centre of the tube. This needle-point forms the pivot on which the supported body turns (fig. 2). There is another method of suspending rods by means of wire rests, made as represented in the diagram (fig. 3), and fastened to a ribbon of silk for support.

FIG. 2.

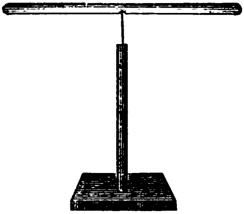
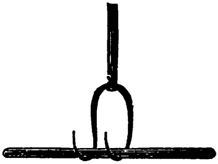


FIG. 3.

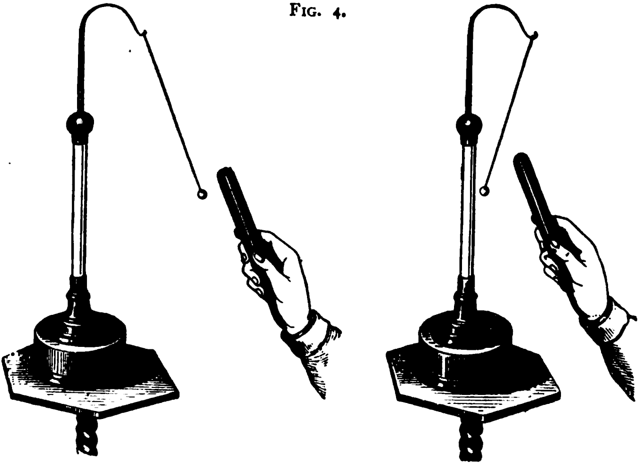


Supports for Excited Rods.

The different actions of glass and sealing-wax, when excited by silk and flannel, on neutral bodies may be plainly seen by their separate influences on a pith-ball suspended by a thread of raw silk. When a glass rod rubbed with silk is brought near the pith-ball, the little ball is attracted to the glass, touches it, and is immediately repelled, and will not for a time again approach the excited glass. If sealing-wax rubbed with flannel be now brought near the repelled pith-ball, the ball will be attracted strongly towards the wax, but in a very short time will be again repelled. An excited glass rod will now attract it. By placing excited rods of glass and wax on either side of the pith-ball it will swing backwards and forwards to wax and glass alternately, as it is repelled from one and attracted towards the other. This forms the *Electric Pendulum.*

Experiment.—Excite glass rod with silk, bring it near suspended pith-ball; notice attraction, contact, then repulsion. Excite sealing-wax with flannel, bring it near the charged ball; the pith-ball is first attracted into contact, and then repelled; the excited glass rod now attracts it. Excite both glass and wax, and place them on each side of the pith-ball, sufficiently near to affect it. Let it first be attracted by the glass; it is then repelled to the wax, and again repelled to the glass, and so forth several times. Had it been attracted to the wax first, it would have been repelled to the glass, and from thence again to the wax, and so on, as in the former case. Show this.

FIG. 4.



Attraction and Repulsion of Pith-Ball.

Heavier bodies are also attracted by highly excited rods, as when glass is rubbed with amalgamed silk, or an ebonite rod is excited with fur.

Experiments.—Take empty egg-shell, which has had its contents blown through holes in the end, let it lie on table, bring excited rod near it; as it moves towards rod, gradually withdraw the rod, the egg-shell will follow it.

Make a cylinder of cartridge-paper 6 in. long, 3 in. diameter, close ends, this may be drawn after excited rod similar to egg-shell.

Balance lath on rounded end of test tube, approach rod to end, notice attraction; draw it round by the attraction of the rod.

Attach feather to a fibre of raw silk ; let it be attracted to glass rod ; it will soon be repelled ; pursue it with the rod ; it will be driven from it, and seem to float in the air.

Rub sticks of ebonite, sulphur, gutta-percha, amber, &c., with fur ; and show that they act similarly on the suspended pith-ball, and balanced lath.

Heat coarse brown paper, and rub it briskly either with the coat-sleeve or with a clothes-brush, it becomes strongly excited, and will attract readily the bodies previously mentioned.

Excite brown paper highly ; lift it by one corner, and place it against the wall ; it will cling to it, and remain there, when the hand is taken away. Hold it over head ; notice attraction of hair.

Warm a drawing-board ; lay a sheet of foreign paper on it ; rub briskly with bottle indiarubber ; if the sheet be then lifted by a corner, it will cling to the wall as the brown paper did.

A ribbon of gutta-percha, drawn rapidly between the fingers, or a film of collodion rubbed with the hand, will show an attractive influence on light bodies. So will a strip of narrow white ribbon drawn between vulcanised indiarubber tubes placed over the fingers, and it will also stick to the wall if placed against it when strongly excited.

Test these.

2. Two Distinct Electrical States and their Mutual Relation.

From these experiments it will be perceived that the electricity derived from glass rubbed with silk differs in its action on the suspended pith-ball from that developed on sealing-wax rubbed with flannel, one attracting what the other repels, and repelling what the other attracts.

By other experiments it may be seen that all electrified bodies exhibit influences similar to one or other of these representative bodies. For a long time it was considered that only one kind of electricity could be produced on glass, when it was rubbed with any rubber, and this was named *vitreous electricity* from *vitrum*, the Latin word for glass.

It was also thought that sealing-wax only gave one kind when similarly rubbed, and this was termed *resinous electricity*, because resin formed a large portion of the substance of the sealing-wax. Recently, however, it has been shown that, when glass was rubbed with catskin, the same kind of electricity was excited on glass, which was thought to be peculiar to sealing-wax, and other resinous substances; also that when sealing-wax was rubbed with gun-cotton, the electricity considered peculiar to glass or vitreous electricity was excited on the wax. The names vitreous and resinous thus lost their significant meaning, and new names, *positive* and *negative*, were substituted by Franklin. Vitreous electricity received the name positive, or + (plus) electricity, and resinous electricity, negative or − (minus) electricity.

The excited bodies belonging to each class may be easily determined by testing them with the electric pendulum. To do this the pith-ball must be charged with glass rubbed with silk. It is strongly attracted by sealing-wax rubbed with flannel. These are termed unlike electricities. All resinous substances, or other substances excited negatively, or charged with negative electricity, will also strongly attract the pith-ball charged by glass rubbed with silk, which is vitreous or positive electricity. On the other hand, all bodies positively excited will act similarly to the glass rod rubbed with silk, they will repel it.

Again, if the pith-ball be charged negatively by sealing-wax rubbed with flannel, the glass rod rubbed with silk, which is positively charged will strongly attract it; but any substance negatively excited will repel it.

Experiments.—Charge pith-ball with sealing-wax rubbed with flannel. Excite glass rod with catskin; strong repulsion. This proves the electricities to be alike. Next charge pith-ball with glass rubbed with silk, then excite sealing-wax with gun-cotton; notice strong repulsion; similar electricity. Charge pith-ball with glass rubbed with silk; excite sealing-wax rubbed with flannel; bring it near charged ball; strong attraction. Test ebonite rubbed with fur in the same way; strong attraction; negatively charged. Rub foreign paper with indiarubber on a warm drawing-board, it repels the pith-ball charged with glass rubbed with silk; similarly charged; positive electricity. Charge ball with sealing-wax rubbed with flannel; bring near it glass rod rubbed with silk; strong attraction, positive. Test strip of white ribbon drawn between vulcanised indiarubber tubes on the fingers in the same way; strong attraction; positively charged. Rub glass rod with catskin; test with sealing-wax charged pith-ball; repulsion; negatively charged. Several other experiments of a similar character will be found on p. 14.

It will be necessary here to test various substances with different rubbers, so that each statement may be confirmed by observation, and not taken for granted because stated to be true.

To account for these differences of electrical condition, theories or ideas were put forward by scientific men. The chief of these were, the 'One Fluid Theory of Franklin,' and the 'Two Fluid Theory of Symmer.'

Theories of Electricity.

(*a*) One Fluid Theory.
(*b*) Two Fluid Theory.

(*a*) **One Fluid Theory.**—The 'One Fluid Theory' was suggested by Franklin; and he endeavoured to explain all electrical phenomena under that idea. According to this theory all bodies contain a certain quantity of a peculiar fluid, which he termed electricity. As long as the body had only its definite quantity, it was in what he considered its neutral condition, and would exhibit no electrical influence on other neutral bodies. When by any means, such as friction, chemical action, or otherwise, more electricity was produced on the body than it would have in its neutral condition, it became positively charged, or excited; and the higher as more electricity was added. It then had its own quantity + electricity received from some other body acting upon it, and was thus said to be charged with + or positive electricity. When electricity was taken from the neutral body, it became charged negatively, or had — electricity, or less electricity remaining on it than its own neutral quantity.

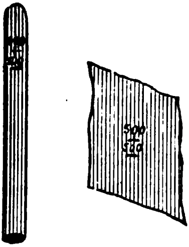
(*b*) **The Two Fluid Theory.**—This is due to Symmer. He considered that the neutral condition of all bodies was owing to two fluids existing in them in equal quantity and of enormous amount. As soon as this equilibrium was disturbed to any extent the body became charged positively or negatively, according to the nature of the rubber and rubbed surfaces.

The process of charging he thought to be due to the decomposition of the two fluids in rod and rubber, one of which accumulated on the surface of the rod and the other on the surface of the rubber. If the rod accumulated positive from the rubber, it gave back an equal quantity of negative to it, so that the amount of electricity remained constant in both, but was re-arranged, one body becoming positively charged and the other negatively, or *vice versâ*.

Both these theories may be represented numerically, and a clearer idea of the charging of bodies conveyed to the pupil. We will deal with the Two Fluid Theory first.

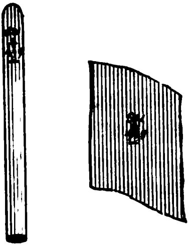
Suppose rod and rubber each to contain 1,000 units of electricity when in the neutral condition, and that this results from both having 500 units of positive and 500 units of negative (fig. 5). Let the rod be glass and the rubber silk. After a little friction the neutral electricity is decomposed in each, and the units are re-arranged. It is found by experiment that in this case positive accumulates on the rod and negative on the rubber. This may be explained in the following way. Suppose the friction liberates one unit of

FIG. 5.



Neutral.

FIG. 6.



Excited.

Rod and Rubber.

positive in the rubber which passes to the rod, it at the same time liberates one unit of negative in the rod which passes to the rubber. ***Each still retains the same total units of electricity*** (1,000), ***but in an altered condition***, the rod having positive in excess and the rubber negative (fig. 6). The two units of positive in the rod and negative in the rubber are now free to affect neutral or excited bodies. If a larger number of units be liberated by the friction, it may be easily perceived and numerically represented, that the rod and rubber will be in a higher state ot electrical excitation by having a larger number of positive and negative units free, that is remaining after the number of the units of the opposite kind is subtracted from the higher number which is produced. In every case we must understand that the body is not charged entirely with positive or negative, but that there is always a certain amount of neutral electricity in all bodies, and that the strength of the positive or negative charge depends upon the number of positive or negative units in excess of the equal quantities of opposite electricities, which keep a portion of the electricity of a body in the neutral condition.

Note.—Any number of units may be assumed to represent the neutral condition of a body. High numbers have been used that it may be easily seen how a large quantity of neutral electricity may exist in a body, and yet it may be highly charged with free positive or free negative electricity. It must be remembered that whatever electrical changes take place in bodies, the total number of units of electricity will remain the same, only differently arranged. This statement will enable the student to understand many difficulties which could not be well understood without it.

The 'One Fluid Theory' may be numerically represented in the following way :—

To account for the charging of the rod and rubber by the 'One Fluid Theory,' let us assume that each body contains 500 units of a peculiar fluid named electricity, and that this is the necessary quantity to keep each in its neutral condition (fig. 7).

If either of these receive more than this amount, it will be charged with the excess positively, and if it lose any, with the loss negatively. On rubbing the rod we will assume that it receives two units of electricity from the rubber. The condition of each will then be represented by fig. 8, and it will be seen that the one has more than its usual quantity, and the other less; or, in other words, one is positively and the other negatively charged. Any other units may be assumed to represent the neutral condition of the bodies, and higher units to express the positive and negative electrification besides those used here for the purpose of illustration.

FIG. 7.

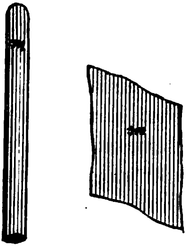
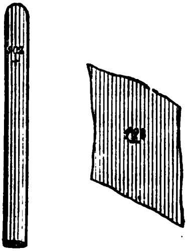


FIG. 8.



Neutral. Rod and Rubber. Excited.

Other Ideas.—Some of our leading scientists consider the electrical excitation to be due to a peculiar condition of the particles of the excited body, or the ether which surrounds the particles and fills the interstices between them. All, however, are merely suppositions, but afford means for the mind to apprehend in some degree this extraordinary form of energy.

3. Positive and Negative Electrification.

It was at first considered that the electricity developed on glass was positive, and on sealing-wax and similar substances negative; experiment, however, proved that the character of the rubber in some cases changed the electrical state of the body rubbed, for negative was found to be produced on vitreous bodies, and positive on resinous. The kind of electricity with which a body is charged may be easily determined by testing it with the electric pendulum. For this purpose the pith-ball should be charged with a known kind of electricity—say, glass rubbed with silk, which we know is positive. In this condition it is strongly attracted by sealing-wax rubbed with flannel, which is also known to be negative. All negatively-charged bodies will act similarly on the pith-ball, charged positively, as the sealing-wax does; they will attract it. On the other hand, if the pith-ball be charged with sealing-wax rubbed with flannel, it will be negative, and will be strongly attracted by the positive electricity which is produced on a glass rod rubbed with silk. Bodies charged with positive electricity also attract the negatively-charged ball. This attraction, however, must not be relied on as indicating definitely a different kind of electricity, for a neutral body would also attract the pith-ball charged with either positive or negative; but the attraction in the case of the neutral body would not be so strong as in the other cases. It is better, therefore, to depend upon repulsion than attraction for determining the kind of electricity with which a body is charged. We have previously seen that when the pith-ball was brought into contact with an excited rod, it was immediately repelled, and would continue to be driven from the rod, while both were electrified similarly. Now, any body charged with the same kind of electricity as the excited rod would act similarly on the charged pith-ball; it would repel the ball. We thus conclude that when the pith-ball has been charged by a glass rod rubbed with silk, if repulsion takes place, when another charged body is brought near it, that that body is charged with positive electricity; or again, when the pith-ball is charged with sealing-wax rubbed with flannel, which is negative, all electrified bodies which repel the ball in this condition are negatively charged.

Negative electricity is best excited on resinous substances, and positive on vitreous. The best rubber for resinous bodies is fur, and for vitreous, silk (amalgamed).

Experiments.—Prove all these statements :—Charge pith-ball with glass rod rubbed with silk for each substance tested, and notice strong attraction of pith-ball, when the following excited substances are brought near it :—

Sealing-wax rubbed with flannel.
Ebonite rubbed with fur.
Sulphur rubbed with flannel.
Brown paper rubbed with clothes-brush.
Gutta-percha rubbed with flannel.
Ribbon of gutta-percha drawn between dry fingers.
Vulcanite, or vulcanised indiarubber, rubbed with fur.
Glass rod rubbed with catskin.

Charge for each substance the pith-ball with sealing-wax rubbed with flannel. Notice strong attraction from the following excited substances :—

Glass rod rubbed with silk.
Sealing-wax rubbed with gun-cotton.
Vulcanite rubbed with gun-cotton.
Ebonite rubbed with gun-cotton.
Ribbon of white silk drawn between fingers, having two pieces of vulcanite placed over them.
Foreign paper rubbed with caoutchouc.
Collodion rubbed with the hand.

Next, test each substance mentioned in its neutral condition with a positively and negatively-charged ball ; and notice that attraction also takes place, but not so strongly as when oppositely charged bodies were near.

Test, again, the character of the electricity on each body in the order already given, and satisfy yourself that your results are accurate by the repulsion of the similarly-charged bodies. If in the first case the pith-ball be charged by sealing-wax rubbed with flannel, repulsion will be apparent as each excited body is presented to it, while the second list will repel the ball if it be charged by the glass rod rubbed with silk.

4. Simultaneous and Equal Development of the two Electrical States.

One kind of electricity cannot be excited in a body without the interchange of an equal quantity of electricity of the opposite sign from the one body to the other. This may be easily understood by reference to the numerical representation of the electrical condition of a charged body, p. 10. But before we examine this portion of our subject fully, it will be necessary to understand the construction and action of Electroscopes.

Electroscopes.

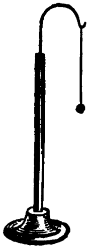
These are apparatus which enable us to see by certain definite effects, whether a body is excited or not ; and if so, to determine with what kind of electricity it is charged.

Electroscopes are usually one of three kinds :—

a. The Electric Pendulum.
b. The Pith-Ball Electroscope.
c. The Gold Leaf Electroscope.

a. **The Electric Pendulum.**—This has been fully described, p. 5. The insulated pith-ball enables us to see that a body is charged by the attractive influence which it exerts on the ball. Again, if the ball be charged with a known kind of electricity, all bodies charged similarly will repel it, while all charged with the opposite kind will strongly attract it. The charge of the pith-ball does not last long, and so it cannot be relied on as an invariable test for any length of time. The electricity is conducted away from the ball by the surrounding air, and, if this be damp or dusty, the discharge is very rapid.

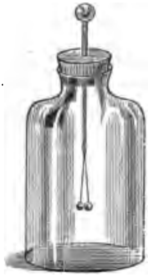
FIG. 9.



Electric Pendulum.

b. **The Pith-Ball Electroscope.**—This has two pith-balls instead of one, and they are securely inclosed in a well-dried glass jar or bottle, to prevent the discharge of the electricity from the balls into the surrounding air. Through the cork, but carefully insulated from it by gutta-percha, shellac, sealing wax, &c., passes a brass rod, the end of which extends into the middle of the jar. To this end of the rod two pith-balls are attached by cotton, and hang at equal distances from it about two inches. To the other end of the rod is fastened a brass ball, which receives the electrical charge; and thus communicates it to the balls, by means of the brass rod and cotton. These immediately show that they are both charged with the same kind of electricity by the repulsion which takes place. Had silk been used instead of cotton to connect the balls they would not have received the necessary charge, neither would they have been affected by the passage of electricity through the rod. Also, if the brass rod be not well insulated from the cork and bottle, the charge will not pass into the balls. For this purpose, and as a secure means of insulation, the stopper should be made of gutta-percha or vulcanite, and generally the cork and neck of the vessel coated with shellac varnish. When the balls are charged with a certain kind of electricity the condition of another charged body may be easily detected by the movement of the balls, as the body approaches the knob at the end of the rod outside the vessel. Should the electricity of the body be similar to the charge of the balls, they gradually diverge further, as the rod approaches; but, if of opposite character, they gradually collapse, returning to their previous position on the withdrawal of the excited rod or body.

Fig. 10.

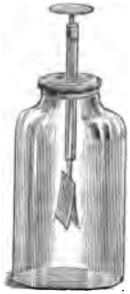


Pith-Ball Electroscope.

c. **The Gold Leaf Electroscope.**—This is similar in its construction to the Pith-Ball Electroscope, as regards the jar, stopper of some insulating substance, or cork with a hole to insulate the brass rod, passing through it into the vessel. To the end of the rod within the jar is fastened a flat cross piece of brass about ¾ in. long, and on each side of this is stuck a strip of gold leaf or Dutch metal about 2 in. long and ¾ in. wide. These should be exactly parallel and equal, and just long enough so that they may not touch the sides of the vessel, when they are extended to the furthest extent. The stopper of the glass jar or bottle should fit securely, so that moïsture may be prevented from getting into the jar, as this interferes with the perfect action of the Electroscope by causing the leaves to collapse quickly after a charge of electricity of either kind has been communicated to them.

The Gold Leaf Electroscope (fig. 11) is the most delicate of either of those described, and is liable to damage from the sudden divergence of the leaves, if a very highly charged body be brought near it. To prevent this a simple apparatus has been made which has received the name of the Proof Plane.

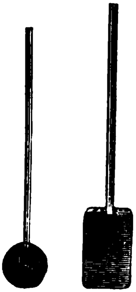
FIG. 11.



Gold Leaf Electroscope.

The Proof Plane consists generally of a small metallic disc, fastened to an insulating rod of some kind. A piece of tin 1 in. in diameter stuck into a thin stick of sealing-wax will do well; or two pieces of silvered paper cut out having the same diameter and stuck together will form a very good collector. This should be stuck with gum to a strip of glass (½ in. wide) coated with shellac varnish. It is well for experimenting to have two Proof Planes of the shape given in the diagrams (figs. 12, 13). The circular one should have a diameter of an inch, and the other should be first made an oblong of 3 in. by 2 in., and have the angles rounded off. The former is used to obtain a small quantity from a highly charged body, and the latter to collect a larger quantity from a body less highly charged.

FIG. 12. FIG. 13.



Proof Planes.

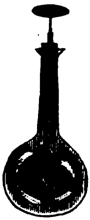
When the Proof Plane is in contact with the excited body, it forms for the time a portion of it, and is consequently charged with the same electricity. On its removal a portion of the body is, as it were, torn off to be tested. This exhibits by its action on the Electroscope the kind of electricity with which the body is charged.

Sometimes instead of the Proof Plane a pith ball coated with tin foil is used. This is hung by a fibre of silk, and is named the '*carrier ball.*'

Use of the Electroscope.

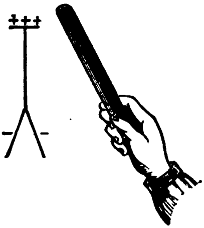
The Electroscope generally used is the Gold Leaf Electroscope, as it exhibits most readily the presence of an excited body; for when a highly charged body is some distance away from it, the leaves show signs of divergence, which increases as the body approaches (fig. 15), but decreases again as it is withdrawn (fig. 16). This is in consequence of the charged body acting upon the neutral electroscope. As soon as it is sufficiently near to influence the electroscope the two electricities are decomposed, and an amount of electricity of the opposite kind is drawn towards the disc, and held there by the presence of the excited body; while a certain portion of the same kind of electricity is repelled into the leaves; and as there are no means for interchange with the earth, the two leaves become charged with similar electricity, and, like the similarly-charged bodies previously described, they repel one another. To determine the kind of electricity with which a body is charged, the electroscope must first be charged with either positive or

FIG. 14.



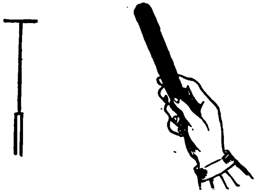
Electroscope.

FIG. 15.



Divergence.

FIG. 16.



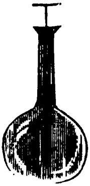
Collapse.

negative electricity, and the effect noticed on bringing a positively or negatively excited body near it.

Method of charging the Electroscope : (*a*) **Positively.**—Bring a negatively excited body near the electroscope, such as sealing-wax rubbed with flannel. This decomposes the neutral electricity of the electroscope, attracting the positive to the disc, but repelling the negative into the leaves, which diverge with free negative electricity. This free negative will pass to the earth, if a way be provided, and an equal quantity of positive will enter the electroscope from the earth at the same time. That this may take place, the electroscope must be put into conducting connection with the earth, either by touching the metallic portion with the hand, or with some suitable substance held in the hand. When this is satisfactorily done, which is seen by the collapse of the leaves, the hand or earth connection is removed; and then the excited rod is withdrawn. Care must be taken that the rod is not withdrawn before the hand is removed, otherwise the repelled negative will again enter the electroscope from the earth, and an equal quantity of positive leave it for the earth, thereby again producing the equal quantities of positive and negative, which restore the previous neutral condition of the electroscope. In this case the leaves remain collapsed when the hand is removed, and show no signs of electrical charge. But if the hand be withdrawn, and then the rod removed, the positive electricity, which was held by the presence of the rod, will spread itself over the electroscope, and that amount of free positive will charge it more or less, which will be shown by the divergence of the gold leaves. If the charge be little the divergence will be slight; but, if high, the leaves will spread further apart.

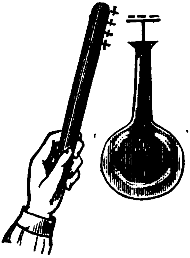
(*b*) **Negatively.**—Bring a positively excited body near the disc of the electroscope. Touch it while the leaves are repelled with positive electricity, and the excited body is near. As in the previous case, positive leaves and negative enters the electroscope. On removing the hand, and then the excited body, the electricity, which was attracted to the upper portion of the electroscope, is now free to spread over disc, rod, and leaves, and its free negative charge is again exhibited by the divergence of the leaves.

FIG. 17.



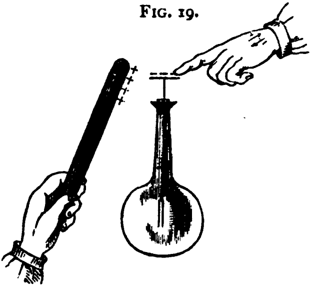
Neutral.

FIG. 18.



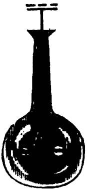
Positive Divergence.

FIG. 19.



Earth Contact.

FIG. 20.



Negative Charge.

Experiments.—Exhibit electric pendulum, bring neutral bodies near, no effect on pith-ball.

Excite rods of various kinds, bring them in succession near the neutral pith-ball; three effects always take place: attraction, charge, repulsion.

Charge pith-ball positively with glass rod rubbed with silk; the kind of electricity of the body to be tested can be easily perceived as it is brought near the pith-ball; if the body be positively charged the pith-ball will be repelled; but if negatively charged, the ball will be strongly attracted. Test this.

Charge pith-ball negatively with sealing-wax rubbed with flannel; negatively charged bodies will repel the ball, but positively charged will strongly attract it. Prove that this is so.

Exhibit pith-ball electroscope, bring neutral bodies near the knob, and into contact with it: no movements of the pith balls noticeable.

Excite rods positively or negatively; bring them in succession *near* the knob: notice repulsion of balls from the free electricity of the same kind driven into them by the presence of the excited body. Withdraw the rod; the balls again assume the neutral condition and come together.

Bring negatively charged body *into contact* with the knob; the electroscope will then be charged with negative electricity, and the balls will be immediately repelled, having similar negative charges. If the body be positive, the electroscope will be charged positively, and the balls will repel one another in this case with positive electricity.

Note.—By contact the balls will have the same kind of electricity as the electrified body has.

Experiments.—Charge the electroscope *without contact.* Bring excited body near the knob—notice repulsion of balls—touch knob or metallic portion of electroscope with hand, rod being still near, balls again come together; remove hand, then remove rod; the balls now diverge with the opposite electricity to that of the exciting body: if that be positive, the balls will be charged negatively; but if negative, the balls will be charged positively.

Exhibit gold leaf electroscope.

Bring neutral bodies of different kinds near and into contact with the disc: no movement apparent in the leaves. Excite bodies slightly: notice gradual but feeble divergence as excited body approaches the disc, and collapse as gradually as the excited body is withdrawn.

Excite bodies more highly: greater divergence is now apparent, violent repulsion as the body is near. Sometimes in this way the leaves are broken, and the electroscope spoiled. Show use of proof plane here. Take charge with small one from strongly charged rod; rub both sides of it over rod, bring it into contact with the disc of the electroscope: the electroscope is thus charged with the same kind of electricity as the excited body.

A gold leaf electroscope is seldom charged by contact, unless the body be very feebly electrified; if the body be highly charged, the proof plane is always used.

The action of an excited body on the gold leaf and pith-ball electroscopes should here be exhibited and contrasted, so that the delicacy and sensitiveness of the former may be fully perceived.

Experiments.—Charge gold leaf electroscope *without contact.*

First, positively.—Test it with positively charged bodies, greater repulsion of leaves. With negatively charged bodies collapse, partially or wholly.

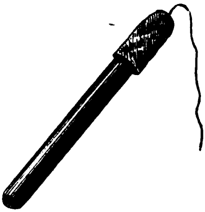
Second, negatively.—Greater repulsion as negatively charged bodies are brought near, but gradual collapse when the body is positively excited.

In these cases, also, it is generally advisable to use the proof plane, for by means of it a more delicate test may be made.

That electricity is produced at the same time in equal quantities in the rubber and rubbed body may be plainly shown by allowing the rubber to remain wrapped around the rod, and placing both together on the disc of the electroscope. While they continue together the leaves of the electroscope are not affected ; but, on withdrawing the rod, the leaves diverge, owing to the influence of the electricity on the rubber charging the electroscope. If the rod be placed again within the rubber, the leaves collapse. This may be easily shown by rubbing sealing-wax with flannel. On removing the rod without allowing the electricity to escape, the leaves will remain charged with the same electricity as the flannel has, and on the approach of the excited wax the gold leaves will fall together, indicating the presence of electricity of the opposite kind, and proving the existence of opposite electricities in rod and rubber.

Faraday arranged a suitable means of illustrating this simultaneous and equal development of the two electricities by using a rod of shellac, and placing over a portion of it a flannel cap, which had a silk string attached to it (fig. 21). On rubbing the flannel round the shellac a few times, electricity of opposite character was excited in both. When the flannel cap was removed by the silk string, both flannel and shellac retained their respective charges ; and when presented to the electric pendulum, charged positively, the rod attracted the pith-ball and the flannel repelled it. Again, when both were brought at the same time on the disc of a neutral gold leaf electroscope, no divergence took place, proving thereby that the two electricities excited in each are equal in quantity.

FIG. 21.



Shellac rod and Flannel cap.

Google

Experiments.—Rub sealing-wax with flannel; let wax remain in flannel, and place both on disc of electroscope, no movement in leaves; draw out wax, leaves diverge with positive electricity of flannel; place wax again in former position, leaves are neutralised and collapse. Rub rod again, and place both on disc as before; draw out wax, leaves are again charged positively; next remove flannel from disc with vulcanised tubes over fingers, or with two pieces of sealing-wax, or gutta-percha, or similar substances, then bring the excited wax near the electroscope: notice the leaves collapse. Get thick round piece of shellac, gutta-percha, sealing-wax, or vulcanite; rub portion of end, about two inches, with a flannel cap, having a silk string attached to it; remove cap by silk string; test kind of electricity in rod and rubber by means of the positively charged pith-ball of the electric pendulum, and equal quantity in each by placing both together on disc of uncharged gold leaf electroscope: no divergence.

5. Action of Electrified Bodies on each other.

It has been previously shown that when a positively or negatively excited or charged body is brought sufficiently near a neutral pith-ball suspended by silk the ball is first attracted, next charged with the same kind of electricity by contact with the body, and lastly repelled. If the ball be charged, and a heavier neutral body be brought near it, the ball will be drawn to the neutral body, and be partially or wholly neutralised by the contact.

When two suspended pith-balls are charged from the same excited body, as, for example, glass rubbed with silk, or sealing-wax rubbed with flannel, and are brought near one another, they repel one another; but, if one be charged from a glass rod rubbed with silk, and the other from sealing-wax rubbed with flannel, they will strongly attract each other.

A striking means of illustrating this is to draw two pieces of narrow white silk ribbon between vulcanite tubes placed over the fingers. They will thus be charged positively, and will, when liberated from the tubes, stand widely apart, Strips of thin gutta-percha, drawn between the fingers, are excited negatively, and will repel one another from being similarly charged. If, however, the two positively charged ribbons be brought near the two negatively excited strips of gutta-percha, strong attraction will take place, and the ribbon and gutta-percha will in each case stick together.

These results are always apparent under similar circumstances—an excited body always attracts, or is attracted by a neutral body; a positively charged body repels a positively charged body; a negatively charged body repels a body similarly excited; while bodies positively and negatively charged attract one another.

The regularity of these actions has led to the establishment of the laws, which apply to electrified bodies, and are termed *the electrical laws.*

These laws are the following :—

1. Neutral bodies are attracted by, or attract electrified bodies.
2. Like electricities repel.
3. Unlike electricities attract.

In these we can trace a similarity to *the magnetic laws.*

1. Magnetic substances are attracted by, or attract, both poles of a magnet.
2. Like poles repel.
3. Unlike poles attract.

Experiments.—Excite glass rod with silk ; show influence on neutral pith-ball.

Excite sealing-wax with flannel ; test similarly.

Charge one pith-ball positively and another negatively ; bring finger near them ; notice the ball is attracted by the hand in both cases ; they will also be attracted by any other neutral body. Charge both balls positively ; show that they repel. Charge both negatively ; exhibit repulsion in this case. Charge one positively and another negatively ; bring them near : the balls attract one another. Place two vulcanised indiarubber tubes over tops of two forefingers ; draw two strips of narrow white silk ribbon between the tubes ; the strips will stand widely apart in consequence of being charged with the same kind of electricity. Each strip is strongly attracted to a neutral body near it, *e.g.* the wall, human body, desk, &c.

Draw two ends of a gutta-percha ribbon through dry fingers ; notice strong repulsion.

Bring excited strips of gutta-percha to excited ribbon : notice effect —strong attraction.

Show also here the action of a magnet on a compass needle, so as to impress the similarity of action between electricity and magnetism.

6. Conductors and Non-Conductors.

All bodies fall under one or other of these divisions. They are either conductors or non-conductors.

Conductors are those substances which allow electricity to pass freely and rapidly through or over them. The more readily this takes place, the better conductor a body is considered to be. As the metals convey electricity most freely, they are the best conductors. Conductors enable the electricity which is generated on any portion of them to spread itself over the whole surface of the body, or to be conveyed to an object at a distance from the excited body.

Non-conductors check or prevent the passage of electricity through or over them, and cause it to accumulate or remain on the body, or parts of the body, on which it is excited. They insulate it, and in consequence are also termed *insulators.*

Some substances, however, do not conduct electricity very freely, nor insulate it very perfectly ; they thus seem to occupy an intermediate stage between the two, and are named semi-conductors.

Semi-conductors are a class of substances which do not allow electricity the free passage of conductors, nor offer the resistance of non-conductors. They afford means for a gradual passage along them, and are in reality imperfect conductors and imperfect insulators. The following substances are familiar examples of each class :—

CONDUCTORS (Non-electrics).	NON-CONDUCTORS (Electrics or Insulators).	SEMI-CONDUCTORS.
The metals.	Fatty oils.	Alcohol.
Well-burnt charcoal.	Chalk.	Ether.
Graphite.	Indiarubber.	Glass powder.
Acids.	Gutta-percha.	Dry wood.

CONDUCTORS (Non-electrics).	NON-CONDUCTORS (Electrics or insulators).	SEMI-CONDUCTORS.
Saline solutions.	Dry paper.	Marble.
Water.	Feathers.	Paper.
Snow.	Hair.	Straw.
Living vegetables.	Silk.	
Living animals.	Glass.	
Flame.	Wax.	
Smoke.	Sulphur.	
Steam.	Resin.	
	Amber.	
	Shellac.	
	Parafine.	

The two main subdivisions may be illustrated in the following manner. If any conductor, held in the naked hand, be rubbed, electricity is generated, but conveyed along its substance through the hand, arm, and body into the earth, as fast as it is produced; and no trace of electricity is apparent in the conductor, even when it is tested by the most delicate electroscopes. On the other hand, if a non-conductor be similarly treated, the portion rubbed soon becomes highly charged; whereas the other end of the body shows no sign of excitation, for the electricity is prevented by the nature of the substance from passing along it. From these two opposite effects being apparent in all bodies, they were at first divided into *non-electrics* and *electrics*, the former corresponding to the conductors, and the latter to the non-conductors.

Non-electrics were so named because it was thought, at that time, that they could not be electrified. Subsequent investigation, however, has shown that, if such bodies be separated from the earth by means of a non-conductor or insulator, or if they be, as is usually termed, insulated, what were known as non-electrics may be excited.

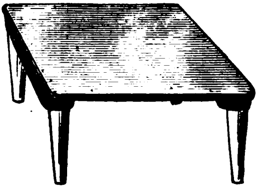
A brass or other metallic rod, held in the bare hand, cannot be electrified, if violently rubbed for a long time; but if it be fastened to an ebonite, gutta-percha, glass, or other non-conducting handle (fig. 23), or if one end be wrapped around carefully with sheets of vulcanised caoutchouc, or layers of silk, the metallic substance may soon be excited by rubbing. A conductor, however, although it be insulated, will not become so highly charged as a non-conductor when similarly rubbed, for in the former case the electricity, as soon as it is generated, spreads over the whole surface of the conductor; whereas in the latter case it is confined to the small portion of the non-conducting substance which has been excited. The charging of a non-electric or conductor may be clearly seen by striking the disc or ball of an electroscope with fur or flannel. Electricity is thus generated and conveyed through the rod, which is insulated in passing through the cork to the leaves. These gradually diverge in consequence of the charge communicated to them, and the kind of electricity may be tested by methods described in p. 21.

FIG. 22.

Brass rod with Glass-handle.

The human body is also a good conductor; and, while in contact with the earth, allows the electricity a free passage, and shows no trace of charge, however rapidly it may be generated; but if the person be placed upon an insulating stool, which is a mahogany board on four glass supports (fig. 23), and then be struck with flannel, fur, or a fox's brush, he becomes so charged that on presenting the hand to the disc of the electroscope the leaves are violently repelled. On bringing the knuckle near the pith-ball of the electric pendulum the ball is first attracted, then charged, and afterwards repelled by the similar electricity of the insulated body. Or, again, if another person, standing in earth contact, bring his knuckle near any part of the charged insulated person's body, sparks may be drawn from him or her. A sheet of gutta-percha, caoutchouc, ebonite, or vulcanite, or

FIG. 23.



Insulating Stool.

a disc of any non-conducting substance placed on the ground for a boy or girl to stand upon, will serve the same purpose as an insulating stool; or a dry, warm drawing-board placed on four dry glass tumblers will also do.

The best means of exhibiting the difference between the passage of electricity through a conductor and an insulator, is to charge an electroscope, and touch the disc with substances selected from the list of conductors mentioned on pp. 25, 26. These cause the leaves to collapse instantly, showing that the electricity, which previously charged the electroscope, had been conducted through the conductor and the body into the earth. The electroscope must be charged separately for each of these experiments. If the electroscope be again charged for the testing of the non-conductors, and substances be taken from the list and presented to the disc, as in the previous case, no movement whatever is noticeable in the leaves; they still remain charged, proving that no electricity passes away through the body which touches the electroscope.

All substances may be easily classified by submitting them to this test. If it cause the leaves of the electroscope to *collapse instantly*, we may certainly consider it to be a *good conductor*; but if the leaves remain divergent, and *show no signs of collapse*, the substance is as certainly proved to be *an insulator.*

Should the charge be observed to pass away *gradually*, not rapidly, as through a conductor, or be apparently checked, as by a non-conductor, the substance should then be included amongst those bodies which are known as *semi-conductors.*

The difference in the passage of electricity for a distance of several feet or yards through a conductor or non-conductor may be strikingly illustrated by using a long thin copper wire, and a string of silk of the same length. Each should be attached in turn to an electroscope by one end, and wound around a glass or ebonite rod by the other. On exciting

UNIVERSITY OF CALIFORNIA.

the rod with the rubber, while rod and rubber are in contact no movement is apparent in the leaves of the electroscope in either case; but, as soon as they are separated the leaves diverge instantly, and widely, when the wire is used; but they are unaffected when silk is the connecting medium; thus proving that the wire conducts the electricity, but the silk checks or resists its passage. Care should be taken that pure silk is used, otherwise the leaves will show a gradual divergence, owing to its becoming a semi-conductor to a certain extent by its mixture with cotton.

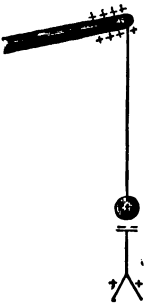
The conductivity of string, when it is wet or dry, may be similarly shown; and from this the effect of dampness and moisture perceived. The influence of a conductor and a non-conductor may also be contrasted by using the electric pendulum to exhibit the latter, and a pith-ball suspended by cotton from a wire, bent similarly to the stand of the pendulum, but in earth contact for the former. The pith-ball of the electric pendulum is first attracted to an excited body, charged, and then repelled; whereas the ball in earth contact is attracted to the excited body, discharges the whole of the electricity if the body be a conductor, or a portion of it if it be a non-conductor, after which the pith-ball is liberated in its neutral condition, as at first.

Insulation.—To enable a conductor to become charged with electricity, it must be insulated, that is, it must be separated from the earth by some non-conducting substance. This is generally done by supporting conductors on glass rods, and in order to render the insulation complete, the glass rods should be coated with shellac varnish to prevent moisture being deposited upon them from the atmosphere. On account of the hygroscopic nature of glass, under certain conditions moisture is deposited in a dewy film very rapidly upon it. This soon destroys the insulation, by changing the insulator into a conductor. Varnishing glass rods is a remedy for this. With every precaution, however, a conductor does not hold its charge for any considerable time, for the moisture and the tiny dust particles in the atmosphere assist in gradually reducing the charge.

Some substances, as ebonite, gutta-percha, sealing-wax, &c., insulate better than glass, as they are not so hygroscopic, and require no shellac varnish to be used on them.

Conduction.—The first experiments on conduction and insulation were performed by Stephen Gray. At first he noticed that a cork stuck in a glass rod attracted light bodies when the rod was excited. He then stuck rods of deal about six inches long into the cork, and these also became electrified on exciting the glass rod. From these he passed to packthread, and found that light bodies were attracted at the end of long lengths of thread. He increased the lengths of the thread, and still the attraction was noticeable. In one experiment he used upwards of 700 feet, and suspended it with thread, but no electricity passed through it. When silk loops were used to support it instead of thread, the electricity passed readily to the end of it. On substituting a thinner wire loop for one of the silk the electricity failed to reach the end of the thread. He then came to the conclusion that the silk prevented the passage of the electricity to the earth, and so confined it to the thread; but the wire loop, when it was in contact with the thread, permitted the electricity to pass to the earth by that means. He thus discovered that the silk was an insulator, but the wire a conductor.

FIG. 24.



Brass ball attached to excited rod by wire.

Continuing his experiments, he also examined other substances, and arranged them under two divisions, ***insulators*** and ***conductors***.

Experiments.—Rub brass rod held in the hand with fur; touch disc of the electroscope; no movement of leaves; conductor, non-electric.

Rub ebonite rod with fur; bring it near the electroscope; leaves diverge; non-conductor or electric.

Charge the electroscope for each experiment with either kind of electricity; touch the disc with as many substances as possible from the list of conductors; the leaves collapse immediately the disc is touched; electricity conducted away to the earth; bodies conductors.

Charge electroscope again for experiments with non-conductors; touch the disc with as many as possible of those which are given in the list; no collapse of leaves; electricity not conducted away from the electroscope; substances non-conductors.

Charge electroscope again, and show gradual discharge, when the disc is touched with the semi-conductors.

Rub brass rod with fur; no movement in leaves when it is brought to the electroscope. Fix insulating handle to brass rod, such as ebonite, gutta-percha, or glass, or wrap one end in sheet-caoutchouc, or in layers of silk; brass rod may now be excited by rubbing, or striking rapidly with fur. Rub with fur; touch electroscope; leaves diverge.

Hold electroscope in the hand; strike the disc a few times with flannel, fur, silk, &c., notice divergence of the leaves, as the electroscope becomes charged.

Let a lad stand on the ground, and hold his hand just above the disc of the electroscope, then strike him with a fox's brush or with fur, no divergence takes place. Place him on the insulating stool, and strike him similarly; leaves now diverge freely. Try it also with lad standing on a sheet of gutta-percha or vulcanised caoutchouc.

Bring knuckle near electric pendulum; notice effect. Let another lad present his knuckle to him, and take a spark.

Fasten long thin copper wire to electroscope; wrap other end around ebonite rod; rub rod, and notice condition of leaves, as rubber remains in contact with rod; separate rubber from rod; strong divergence.

Attach silk string similarly, after excitation, and separation of rubber from rod; no divergence of the leaves whatever.

Test dry string and wet string similarly, and notice effects.

Show the need of insulation for a conductor.

Place a conductor on a brass support, no charge can be imparted to it. Test again, when supported on a clean glass rod; the conductor is charged, except under very favourable conditions, with difficulty. Place conductor on glass rod coated with shellac varnish, charged easily. Notice this. Explain and understand the cause of these different effects.

Push cork into the end of a glass tube; excite tube; electricity also charges the cork; show it by repelling similarly charged pith-ball, and by its action on the leaves of the electroscope.

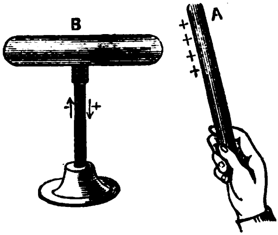
Stick rod of deal about 6 in. long into the cork; rub tube again; show repulsion of pith-ball, and divergence of the leaves, as before, when wood is brought near them. Suspend small brass ball at the end of a wire, and again at the end of a silk string, and show their effect on an electroscope. Attach long length of thin copper wire to electroscope and rod. Excite rod, leaves diverge, touch wire in any place with conductor; notice collapse of leaves; touch with insulator, leaves unaffected.

7. Effect of connecting a Conductor with the Earth.

In the last division of the subject it has been shown that, in order that a conducting substance *may be electrified*, it must not be in contact, or in conducting connection with the earth, but *must be insulated*. That a conductor also *may retain the charge* which it receives from the action of an electrified body, it *must be kept from earth connection by insulation*. The accompanying diagrams will make this clear.

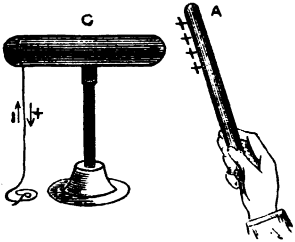
Let the positively excited rod, A, be brought in succession near the conductors B and C, one of which (fig. 25) is supported on a rod of brass, and the other (fig. 26) on a rod of varnished glass, but connected with the earth by means of a wire. Both of the conductors are thus in earth contact. Now, as soon as the electrified body is brought near enough to act upon the conductor, the first effect produced is to decompose a certain amount of neutral electricity in the conductor; negative, the opposite kind of electricity, is

FIG. 25.



Conductor on brass support.

FIG. 26.



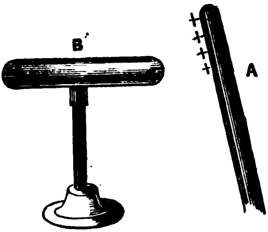
Conductor on glass connected with earth by wire.

attracted towards the rod, and positive, the similar kind, is repelled to the earth. That the number of electrical units may remain constant in the conductor, the same quantity of negative is considered to pass from the earth to the conductor, as positive to leave the conductor for the earth.

On removing the rod, the repelled positive returns from the earth, and the equal amount of negative passes at the same instant to the earth, thus again producing the neutral condition of the conductor as it was before its disturbance by the presence of the electrified body.

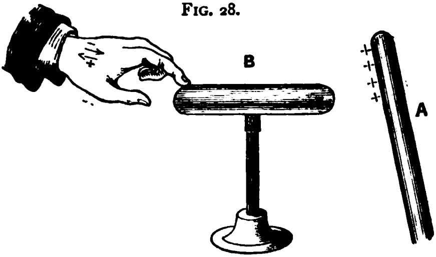
Should the conductor be perfectly insulated by being fixed on some non-conducting support, such as ebonite, gutta-percha, sealing-wax, or glass coated with shellac varnish, the effect of the approach of an electrified body towards it is simply to decompose and rearrange the two electricities, as shown in the diagram (fig. 27). On the excited rod A approaching B, its first effect, as before explained, is to decompose the two electricities, and, in accordance with the electrical laws the negative is drawn towards A, while the positive is repelled from it. As there is now no earth connection, the interchange between the conductor and the earth cannot take place as before. The repelled positive, however, is in such a condition that it will exchange for an equal quantity of negative (fig. 28) if any means be provided for conducting

FIG. 27.



Insulated Conducto.

FIG. 28.



Decomposed Conductor touched with the hand.

connection with the earth or any conductor larger than itself.

The positive is liberated by the presence of the positively excited rod, and is thus rendered *free* to pass to the earth or other large conductor ; while the negative is held *captive* by the attractive influence of the rod, and is unable to move from the part of the conductor, where it is produced, until the rod be withdrawn or discharged. When in this condition it is termed *bound.*

It may here be stated that the electrical action which takes place between an excited body and a conductor, when they are *not in contact* with each other, is named *Induction*, and that the decomposed electricity of a conductor, when under the inductive influence of an electrified body, is either *free* or *bound.*

Free Electricity.—Electricity is termed free, when it is so far liberated from the neutral condition in which it previously existed, that it is enabled to exhibit its attractive and repelling influences on outside bodies, or to pass to the earth or other conductor, if a suitable conducting means be provided for its passage. The charge excited on a rod by friction is free electricity ; so is that which causes the leaves of the electroscope to diverge, and the electricity which passes to the earth from a conductor through the inductive action of an electrified body, so also is that which is apparent at the further extremity of an insulated conductor when under induction, and the charge of the prime conductor of the electrical machine.

Bound Electricity.—Electricity is considered bound when, after it is separated from its neutral condition, it is held captive or paralysed by the action of some electrified body near it, and is thereby rendered powerless to exert its influence on outside bodies. Under certain conditions, on the withdrawal of the electrified body, the liberated electricity charges the conductor, and is immediately transformed from bound to free ; for then it is capable of affecting other charged or neutral bodies.

The electricities of both rod and rubber are bound, after they are rubbed together, until separation takes place. The electricity on the disc of the electroscope is bound while it is under induction, and will not pass away although the disc be brought into earth contact. That also which is produced on the end of the conductor near the inducing body is also bound; and so are the electricities on each side of a condenser or Leyden jar. Bound electricity is always of the opposite character to that which retains it.

Specific Inductive Capacity.—It was established by Professor Faraday, that for an excited body to act upon a conductor by induction, some substance must exist between the two through which the electricity may be imparted. In our examples on induction, air is understood to be present. Some substances, as, for example, varnished glass, sealing-wax, ebonite, &c., allow this action to take place at the same distances much more freely than air. Those substances which enable electricity to act most strongly through them are said to have the *highest specific inductive capacity.* Dry air is superior to moist air in this respect.

A conductor may be charged either positively or negatively similar to the method of charging the electroscope, pp. 19, 20.

Experiments.—Place conductor on brass rod; test it with electroscope; no action on leaves. Bring positively excited rod near conductor; withdraw it; test conductor again with electroscope: no charge.

Support conductor on insulating rod of varnished glass, ebonite, or other non-conducting substance; attach thin copper wire to the end of the conductor and the disc of the electroscope. Bring excited rod near the conductor; notice the divergence of the leaves of the electroscope as the rod approaches. Withdraw rod; notice gradual collapse of the leaves as the distance increases. Refer to similar action taking place in all bodies under induction, although in most cases invisible. Repeat the last experiment, and while the leaves are divergent remove the wire with some insulating substance, such as vulcanite tubes over fingers; test the character of the charge; show it to be positive or negative according as the leaves become more divergent by a glass rod rubbed with silk, or stick of sealing-wax excited with flannel.

Let pith-ball rest against the end of the conductor away from the portion next the rod; bring excited rod near conductor; notice the repulsion of the pith-ball, being charged with the free electricity of the conductor. Withdraw rod, electricities recombine; conductor neutralised, ball also neutralised, and is attracted towards conductor, after which it hangs vertically as at first. Repeat a portion of this experiment, and while the pith-ball is repelled by the free electricity, remove it from the influence of the conductor, and test its character, as in the previous example. Bring glass rod rubbed with silk to insulated conductor; touch the conductor in any part with the finger while it is under induction, remove the hand, and then withdraw the exciting rod; the conductor will remain charged with the opposite electricity from that of the exciting body. Test this by showing the repulsion of the pith-ball of the electric pendulum, charged negatively; take a portion of it with a proof plane, and test with an electroscope charged negatively; leaves diverge further—same electricity.

8. Experiments illustrating the relation between the Primary Electrical Charge and the Correlatively Induced Charge.

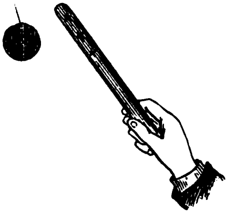
As explained in the last division of the subject, an excited or charged body acts inductively on a neutral body, and the successive steps of that action are:—

1. The decomposition of the neutral fluids.
2. The rearrangement of the two electricities; the opposite kind being attracted towards, and the same kind repelled from the electrified body.

Should the charged body be withdrawn, the two electricities recombine, and the conductor returns again to its neutral condition. This may be plainly shown by the action of a charged body on the gold-leaf electroscope. As the body approaches the electroscope the leaves gradually diverge, but collapse again as it is withdrawn. A similar change in the condition of the electricity of the body must be imagined under all cases of induction.

We will examine first the action of a positively excited rod on the pith-ball of the electric pendulum (fig. 29). As the rod approaches the pith-ball, near enough to affect it, the first influence is to decompose the neutral electricities of the ball, and the next is to rearrange them ; negative electricity is attracted to the part of the ball nearest the rod, and positive is repelled to the part away from it. Now, from the action of the law of inverse squares, the attraction is greater between the positive rod and the negative part of the ball, than the repulsion between the rod and the positive part, and therefore the ball is attracted towards and touches the rod. It then gives a portion of its negative to, and receives an equal amount of positive from the rod, and thus becomes charged with a certain quantity of free positive. The ball is now repelled from the rod, and this repulsion continues until the free positive is discharged, either by the moisture of the atmosphere, the dust particles in the air, or by touching some body which permits its discharge. This is what is known as charging by contact.

FIG. 29.

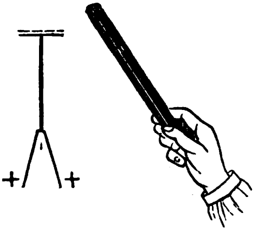


Action on Neutral Pith-Ball.

An electroscope is similarly acted upon by an excited body, as may be understood from the accompanying diagram (fig. 30).

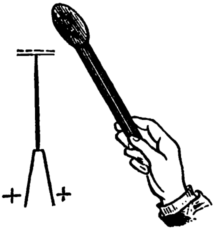
If the rod be brought into contact with the disc or ball, equal quantities of negative pass from the electroscope to the rod and positive from the rod to the electroscope. The electroscope thus becomes charged with a greater quantity

FIG. 30.



Action on Gold Leaf Electroscope.

FIG. 31.



Inductive action from Proof Plane.

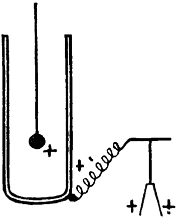
of free positive, and the leaves diverge further in consequence. With a highly charged rod this is a dangerous experiment to attempt, as it is likely to break the leaves, particularly if the electroscope be a sensitive one. To avoid this, the proof plane is used, and by means of it small charges may be removed from the surface of the charged body to be tested by the electroscope (fig. 31).

When this is done, the influence on the electroscope is similar to that exerted by the rod, but the leaves are much less violently disturbed.

Faraday's Ice-pail Experiments.

The character and quantity of the induced electricity may be clearly seen and easily detected by what is known as Faraday's Ice-pail Experiment. The ordinary ice-pail is made of pewter, and is about seven inches in diameter and ten inches deep (fig. 32). This must be insulated, and connected on the outside by means of a copper wire with a gold-leaf electroscope. On bringing a positively charged brass ball, held by a long silk string, into the interior of the ice-pail, negative electricity is induced on the inner and positive on the outer surface of the vessel. The free positive of the exterior of the pail causes the leaves of the electroscope to diverge gradually as the ball is lowered into it, until it has sunk about three inches into the vessel, after which no further divergence takes place. If now the ball be lowered, so as to touch the bottom of the pail, and then be withdrawn, the ball will have become neutralised by interchanging with the negative of the pail, but the leaves of the electroscope will not diverge further; thus proving that the charge, produced on the outside of the pail by induction from the charged ball, was equal to that which it received by contact with it.

Fig. 32.

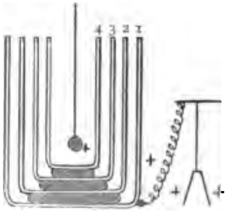


One Insulated Ice-pail.

Faraday varied the experiment by using four ice-pails, placed in one another (fig. 33), but separated from each other by layers of shellac, thus securing the necessary insulation. The outside of the outer pail was again insulated, and connected by a thin copper wire with a gold-leaf electroscope. When the charged ball was brought into the inner pail of the series, the leaves of the electroscope diverged in the same manner as they would have done if only one pail were used. This arose from the inductive action of the inner pail on the one adjacent to it, that one on the next, &c., until the free positive of the outer vessel through the wire connection charged the electroscope, and caused the leaves to diverge. If now the ball be withdrawn, the leaves collapse, showing that the decomposed electricities in the pails had again recombined, and the series returned once more to the neutral condition. If, however, before withdrawal, the ball be allowed to touch the inner pail, it is charged with the same kind of electricity as the charge of the ball, and, as in the previous case, the ball is neutralised, but the leaves show no further divergence.

If now the inner positively charged pail be removed by some insulating substance, the remaining pails are neutralised, and the leaves immediately fall together, but diverge again on its being replaced. If the series be connected in order from the outer pail, as 1 and 2, 2 and 3, 3 and 4, or 1, 2, 3, 4, no alteration in the leaves of the electroscope will be apparent.

Fig. 33.



Four Insulated Ice-pails.

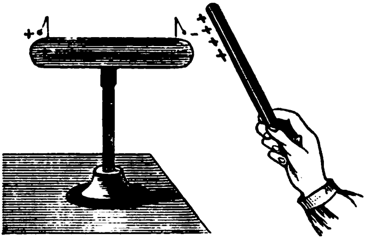
Again if, while the pails are under the inductive action of the charged ball, the inner pail, 4, be connected with the earth, the free positive escapes, and the remaining pails at once return to their neutral condition, which is seen by the collapse of the leaves. The negative of the inner pail is unable to disturb the neutral condition of the other pails, because it is held bound by the presence of the positively charged ball.

Should 3 be connected with the earth, 2 and 1 immediately become neutralised; and, lastly, if 2 be placed in earth connection, 1 is restored to the neutral condition.

Action on Conductors.

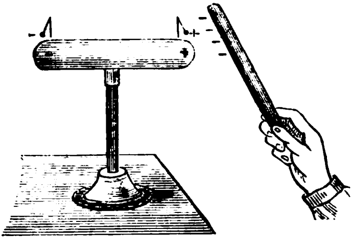
A cylindrical conductor may be used to exhibit the influence of an excited body upon it by attaching a small electric pendulum to each end of it. Suppose a positively charged rod be brought near the conductor, the pith-balls on the ends immediately rise—the one nearest the rod charged with negative electricity, and the one away from it charged with positive (fig. 34). If the rod be withdrawn, the pith balls instantly fall, and the conductor is again neutralised. Should a negatively charged rod be used, the pith balls also rise, but in this case charged with opposite electricities to the former example (fig. 35). On the withdrawal of the rod the two electricities again recombine. The kind of electricity charging the pith-balls in each case is shown by the repulsion, which is noticeable when they are tested by a glass rod rubbed with silk and a sealing-wax rod rubbed with flannel.

FIG. 34.



Effect of the presence of a Positively Excited Rod.

FIG. 35.



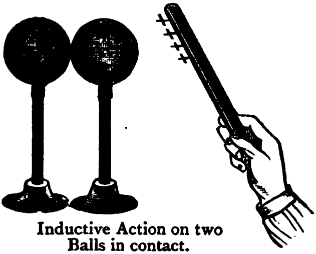
Effect of the presence of a Negatively Excited Rod.

When two equal brass or tin-foil-covered wooden spheres are in contact and acted upon inductively by an excited body, one ball becomes charged positively and the other negatively

—the nearer one with the opposite kind and the further with the same kind of electricity as that of the inducing body.

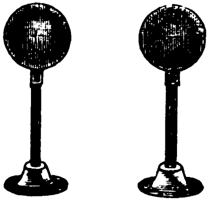
These two charges are nearly equal, but not exactly so, as the intensity is modified by the 'law of inverse squares,' which is applicable to electricity as to magnetism (see 'Magnetism,' p. 22). The ball next the inducing body would have a slightly higher charge of the opposite kind of electricity to the other. If they be separated while they are under the inductive influence of the charged body each will retain for a time its own particular charge, which may be tested by means of the electroscope, and the character and quantity of each easily exhibited.

FIG. 36.



Inductive Action on two Balls in contact.

FIG. 37.



Separation of Balls while under Induction.

If, however, when in this condition, they be brought very near or into contact, they immediately neutralise one another by the interchange of electricity from ball to ball.

FIG. 38.

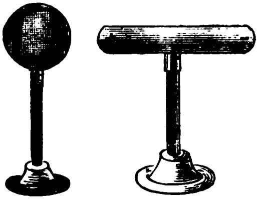
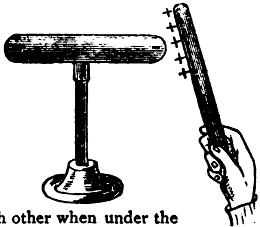


FIG. 39.



Action of Conductors on each other when under the influence of a Charged Body.

When two or more insulated conductors are placed near one another (figs. 38, 39), the decomposed electricity of the first influences the next, and this the next, &c., similarly to the action of a magnet on neighbouring pieces of soft iron. (See Magnetism, p. 17).

The Electrophorus.

A most important piece of apparatus for exhibiting the induced charge obtained from the action of the primary charge is the electrophorus. This consists of two circular plates, one of which is about 2 inches less in diameter than the other. The larger forms the base, or portion of the apparatus to be excited, and must be of some insulating substance—generally a cake of resin or ebonite—contained in a tin dish which is named the 'sole.' This forms *the generating plate.* The smaller is the conductor, and must be of metal. It is generally made of brass or tin. This is known as *the collecting plate.* To this plate an insulating handle is attached, and the apparatus is complete.

FIG. 40.

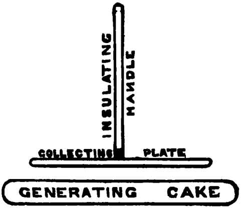


FIG. 41.

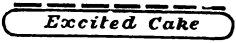


FIG. 42.

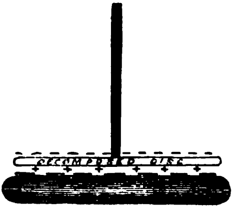


FIG. 43.

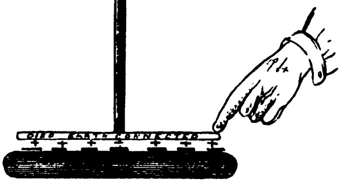
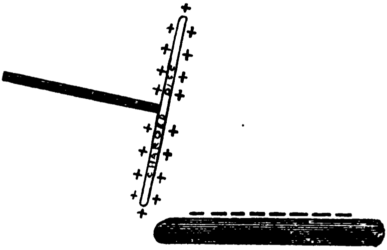


FIG. 44.



Positively charged Disc.

Method of Charging.—To charge the electrophorus the cake must first be excited. This is usually done by warming its surface and then striking it smartly two or three times, or rubbing it briskly with fur or flannel, which causes it to be electrified negatively. The conductor, held by the insulating handle, is now lowered gradually upon it. As this approaches, the electricity of the base acts inductively on the conductor, decomposes the neutral electricity of the metal plate, and attracts positive electricity to the lower face, but repels negative to the upper. Should the conductor be withdrawn again without being touched with the hand, or otherwise brought into earth contact, the two electricities will recombine, and the neutral condition be again produced.

But if, while the conductor rests upon the excited cake and is under the inductive action of it, the upper surface of the conductor be touched by the finger, the free negative passes to the earth, and an equal quantity of positive enters the disc from the earth. The hand should then be removed, so as to break the earth connection, and the conductor be lifted by the insulating handle. It will then be found to be highly charged with free positive electricity, and if the knuckle be brought to the edge of the disc a spark will be seen, and a feeble crack heard, which is the result of positive passing from the disc to the knuckle, and negative at the same time passing from the knuckle to the disc. If a pith-ball, or a number of pith-balls, be laid on the conductor before it is charged, on charging it as described and lifting it from the cake, the pith-balls are immediately and violently repelled, being charged with the same kind of electricity as the conductor. The kind of electricity charging the disc may be tested by bringing it near an electric pendulum or gold-leaf electroscope charged positively. The free positive of the conductor may also by means of several charges be employed to charge a Leyden jar. These successive charges may be obtained from the same excited cake, for as the charging is by induction and not by contact, little electricity is lost by the cake when the disc is charged. On this point, Professor Guthrie writes :—'Scarcely any actual interchange between the + of the brass and the – of the cake takes place, because the two surfaces only touch one another in a few points, and the resinous substance, being an exceedingly bad conductor, does not permit the recharging of the discharged points.'

To avoid the necessity of touching the collecting plate of the electrophorus every time it is required to charge it, a brass pin, or a series of pins, may be brought from the sole through the cake to its surface, so as to be in contact with the upper disc when it is placed upon the excited cake. In this way the free negative escapes from the collecting plate to the earth through the pin or pins, and an equal quantity of free positive passes by the same means from the earth to it. Sometimes a strip of tin-foil is brought from the sole over the cake to meet the edge of the upper disc, and this offers a similar passage for interchange with the earth as the pin arrangement does. In this way a rapid succession of charges may be communicated to, and sparks obtained from the collecting plate of an electrophorus, and a Leyden jar be charged most quickly from it.

Experiments.—Excite glass rod with silk ; bring it to the disc or knob of the electroscope ; notice divergence of the leaves. Withdraw it ; the leaves collapse.

Excite sealing-wax with flannel ; test similarly : similar results.

Test electric pendulum with excited glass and excited wax ; notice movements of pith-ball in each case.

Test electroscope with highly-excited rod: the leaves diverge when the rod is some distance away.

Draw a proof-plane over excited rod; bring it near to, or on disc or ball of electroscope: similar action apparent.

Obtain metallic vessel 7 inches in diameter and 10 inches deep. Insulate it. Attach wire to outside of the vessel and to the disc of electroscope. Notice divergence as positively charged ball is lowered; withdraw ball: leaves collapse. Lower ball again, and let it touch the bottom of the vessel: no increase in divergence apparent after the ball has sunk below 3 inches.

If possible, test four similar vessels, but of slightly different sizes, and insulated from one another and the earth. Charge the inner one positively: the leaves of the electroscope diverge with positive electricity. Remove this charged inner vessel by means of silk handles, which should be fastened to it with sealing-wax: leaves collapse; other vessels neutralised. Connect in succession, while under inductive influence of charged body, 4, 3, 2, 1 with the earth: the leaves collapse—due to free electricity from each interchanging with earth and neutralising outer vessels.

Fix a small electric pendulum at each end of a conductor; bring excited rod near: the pith balls are repelled. Test kind of electricity of each ball by using positively and negatively charged rods; notice repulsion: similar electricity.

Bring two equal spherical balls into contact; let an excited rod be brought near them, so as to decompose the electricity. Remove the further ball, then withdraw the rod: the two balls will be charged with opposite electricities; that further away has similar electricity to the excited rod, and that near the opposite kind. Test this by means of proof-plane and electroscope. Charge balls again in this way, then bring them very near to one another: a feeble spark will be visible, and the balls become neutralised.

Excite cake of electrophorus by rubbing with fur or flannel, or striking with a fox's brush; bring conductor on excited cake, and withdraw it again without having brought it into earth contact; test with electroscope: no trace of electricity.

Bring conductor again on excited cake; now touch it with finger, remove finger, and lift conductor by insulating handle; present knuckle to conductor; spark passes.

Charge conductor again similarly, bring disc towards the electroscope; notice divergence of the leaves when it is some distance away.

Charge electroscope with positive electricity; the leaves diverge further as the disc is brought near it. Charge another electroscope negatively : the leaves collapse gradually as the disc approaches. The proof-plane should be used if the charge is very high.

Fasten thin copper wire to the disc of the electrophorus, and attach the other end to the electroscope ; notice movement of leaves as the disc is brought on the excited cake ; collapse as disc is touched, and strong divergence as disc is lifted from cake.

Bend tin-foil from sole over edge of cake to meet disc ; excite cake, and obtain a succession of charges from excited cake ; charge Leyden jar by means of a series of sparks from charged disc.

9. Frictional Electrical Machines.

There are two kinds of frictional electrical machines—the cylinder machine and the plate machine. The essential parts of each are the rubber, the cylinder or plate on which the electricity is excited, and the prime conductor on which it is accumulated. In these respects they resemble the electrophorus, which is the first form of electrical machine.

The Cylinder Machine was first developed by, and its present form is due to, Gordon ; while the ordinary plate machine owes its origin some say to Planta, others to Van Marum. A later variety of plate machine was developed by Winter.

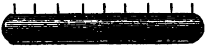
The Cylinder Machine.—The rubber of the machine consists of a long pad of horsehair covered with soft leather about three-quarters of the length of the cylinder. Before use it is smeared with bisulphide of tin, or an amalgam consisting of one part of zinc, one part of tin, and two parts ot mercury, laid on with lard, to develop the electricity more freely on the surface of the cylinder or plate. The rubber may be insulated by being fixed on a glass support coated with shellac varnish, or it may be fastened to a wooden stand, and thus be in earth connection. If the rubber be insulated, in order that the prime conductor may be charged, a wire or chain must pass from it to some conducting connection with the earth, as *e.g.* the ground, gas-fittings, &c., or the chain may be held in the hand of a person standing on the ground.

A flap of silk extends from the rubber almost to the prime conductor to prevent the electricity escaping into the atmosphere in its passage from one to the other. Sometimes a brass conductor is fixed at the back of the rubber for the accumulation of negative electricity.

The Cylinder is of different sizes, but in all cases it is similarly blown, so that there may be projections at each end. Securely fastened to these by means of cement are wooden caps which carry the axles, and rest in two wooden supports which are firmly fixed into the wooden base. One axle is longer than the other, and to this longer one the handle for turning the cylinder is fixed.

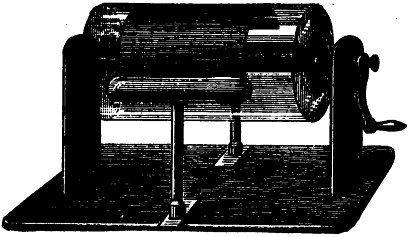
The Prime Conductor consists of a hollow cylinder of brass or tin, or it may be made of wood coated smoothly with tin-foil. It is placed about the same height as the rubber, but on the opposite side of the cylinder, and is supported on a glass rod coated with shellac varnish. A row of points projects from the portion of the prime conductor facing the cylinder. These are sometimes termed the comb or rake, and are about $\frac{1}{4}$ inch long, and brought within about $\frac{1}{8}$ inch from the surface of the cylinder.

FIG. 45.



Comb or Rake.

FIG. 46.



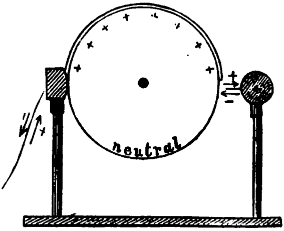
Cylinder Machine.

Both rubber and prime conductor are regulated by a foot, which moves in a groove and is secured by a screw. A knob is generally fixed to the prime conductor, when it is long in proportion to the width. Great care should be taken that no points or sharp edges form a portion of the prime conductor, except those turned towards the cylinder, otherwise the electricity will disappear as rapidly as it is produced.

Charging the Cylinder Machine.—This machine may be charged either positively or negatively. Its usual charge is positive, which is accumulated on the prime conductor; but when it is charged negatively the negative is accumulated on a conductor, which is insulated and attached to the rubber.

Positive Charge.—To secure this the rubber must first be put into earth contact, and the prime conductor be insulated. On turning the cylinder the glass becomes charged positively by the friction with the rubber, and the latter negatively, in accordance with the theory adopted in explaining the charging of the glass rod with the silk rubber (p. 10). The rubber, however, being in earth contact, is enabled to interchange a certain amount of free negative electricity with the neutral of the earth, and thus to keep its units of electricity constant, and to decompose a larger quantity of the electricity of the cylinder. The excited cylinder passes from the rubber, charged with positive electricity, towards the prime conductor, the flap of oiled silk preventing its being acted upon by the atmosphere. As it approaches the prime conductor in a high state of positive charge, it acts by induction on the prime conductor, attracting the negative but repelling the positive. The row of points of the prime conductor, facing the cylinder, permits negative to rush out against the cylinder and positive to pass in from it, thus securing equal units of electricity in conductor and cylinder, but in an altered condition. The prime conductor, which was previously neutral, becomes rapidly and highly charged with positive, while the cylinder is as rapidly neutralised. It continues in this neutral state as it passes from the prime conductor to

FIG. 47.



Effect of turning Cylinder.

the rubber. Here the electricities are again decomposed, and the cylinder receives another positive charge. This is again neutralised on reaching the prime conductor, and thus regularly and uniformly do the charging and discharging ot the cylinder proceed. From this explanation it will be understood that, when the cylinder machine is at work, the part between the rubber and the prime conductor is positively charged, and the portion between the prime conductor and rubber is in the neutral condition (fig. 47).

Limit of the charge of the Prime Conductor.

The positive of the prime conductor will only acquire a certain tension, which depends on the *condition of the atmosphere*; and, when that point is reached, it will interchange with the adjacent air as rapidly as it receives an additional charge. The *presence of dust particles in the air* also tends to reduce the tension. It is also very much affected by the *condition of the machine itself.* If it be cold, little effect will be apparent from the action of the excited cylinder on the prime conductor; but, if the machine be well warmed, on turning the cylinder, the electricity of the prime conductor rapidly acquires high tension. To retain a uniformly high charge the cylinder must continue to turn, otherwise a more or less rapid discharge will take place into the surrounding atmosphere. This may be plainly shown by attaching a Henley's Quadrant Electrometer to the prime conductor, and noticing the rise and fall of the pith-ball under different conditions.

Negative Charge.—To obtain a negative charge *the rubber must be insulated*, and the prime conductor put into conducting earth connection. It is also necessary, if a large quantity of negative electricity is to be accumulated, that a cylindrical brass conductor should be attached to the rubber.

When the cylinder is turned, as before described, positive electricity is generated on the glass, and negative on the rubber. The free negative is unable to interchange with positive from the earth, and so it accumulates with increasing tension about the rubber, or the conductor attached to it. The cylinder then passes to the prime conductor highly charged with positive. Here by induction through the points, and by means of the earth connection, there is an interchange of electricity, positive escapes from the cylinder to the earth, and negative passes from the earth to the cylinder. This neutralises the positive charge of the cylinder, which again passes to the rubber to yield up an equal quantity of negative for a similar amount of positive as at first.

The amount of charge may be ascertained, as in the previous case, by attaching a Quadrant Electrometer to the conductor at the back of the rubber. The tension is dependent on the state of the atmosphere as regards moisture at the time of the experiment.

Methods of showing Tension.

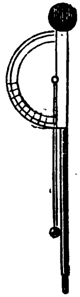
The tension of the electricity of the prime conductor, or the force with which a discharge takes place towards an object near it, is easily determined by bringing the knuckle of the finger to the prime conductor. If the tension be high, the spark will be long, loud, sharp, and stinging ; but, if it be low, the spark, if any, will be feeble in all respects, and scarcely perceptible. A rounded knob at the end of a short rod of brass is the best means for testing this ; for then the operator does not feel the pricking or stinging of the high tension sparks, as they strike the knob held in the hand. The tips of the fingers when presented to the conductor reduce the tension of the discharge ; and if a sharp point be used no spark can be drawn from the prime conductor, and the pith-ball of the Electrometer hangs vertically, as if no charge had been communicated to it. The sharper the point, the more successful is this experiment.

Henley's Quadrant Electrometer.

This is an apparatus which is used for exhibiting the tension of the electricity of a charged body. It consists of a brass rod about 6 inches long, arranged at the bottom to fit into small holes, which are sometimes left in electrical apparatus for that purpose, while the top terminates in a small knob (fig. 48).

To this rod is attached a semicircle of ivory, wood, or cardboard, graduated into degrees; and from its centre is suspended a light wooden rod, having a small pith-ball attached to the end of it. In its ordinary condition the pith-ball hangs vertically downwards. When the brass rod of the Electrometer is attached to an electrified conductor, it immediately becomes charged with similar electricity. The pith-ball, resting against the rod, is similarly charged, and immediately repelled. The force of repulsion is measured by the number of degrees, shown on the semicircle by the rod to which the pith-ball is attached, and this angle is an indication of the tension of the free electricity in the body.

FIG. 48.



Henley's Quadrant Electrometer.

The gradual loss of electricity into the atmosphere, after the prime conductor has been charged, is clearly seen by placing an Electrometer on the conductor, charging it with electricity of high tension, and then watching the gradual fall of the pith-ball, as the charge is being reduced. The effect of presenting the knuckle, or a point held in the hand, to a highly charged conductor is also clearly seen by the sudden fall of the pith-ball to its vertical position.

The Plate Machine.

The Plate Machine has the same essential parts as the cylinder, the only difference being that the cylinder is replaced by a circular glass plate having a thickness of about

¼ in. The rubbers are securely fixed on both sides of the plate over each other, one pair at the bottom, and the other at the top of it; and the branches of the prime conductor carrying the points or comb, sometimes termed the rake, are situated midway between the rubbers. In some machines there is a row of points on each side of the plate; but in others only one row against the side of the plate nearest the prime conductor. From the rubbers above and below on both sides of the plate, oiled-silk flaps extend almost to the points of the prime conductor, to retain the positive charge as in the cylinder machine. The prime conductor is insulated, and the rubbers are in suitable earth connection by means of the wooden supports. Positive electricity is thus easily and rapidly developed on the prime conductor. For experimental purposes the plate machine is better than the cylinder. An ebonite plate is sometimes used instead of a glass plate, and then the prime conductor is charged with negative electricity.

FIG. 49.

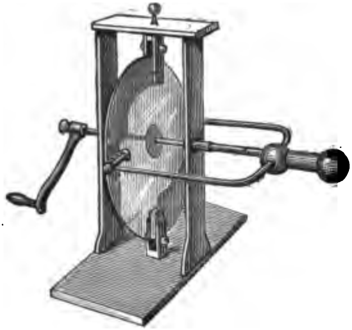


Plate Machine.

A metal plate might be used instead of either, provided it be well insulated from the spindle, but as the generated electricity would spread over the whole surface of the plate, for the metal is a good conductor, instead of remaining on the portion of it where it was excited, the electricity from such an arrangement would have very low tension.

Method of Charging.

This is exactly similar to the charging of the cylinder, and need not be repeated here, if that be understood, see

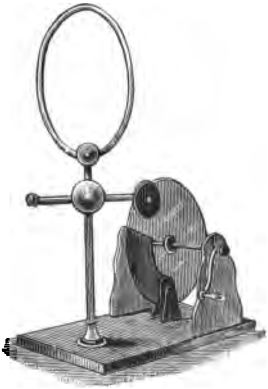
UNIVERSITY

p. 48. The friction of the rubbers and plate decomposes the electricities of each, and the plate becomes charged positively. This positively excited plate causes positive to accumulate on the prime conductor. The positive charge can only acquire a certain tension, for the atmosphere acts upon it in such a way that when that tension is reached, the air discharges as fast as the machine excites it. A machine thoroughly insulated, as, for example, placed on a table with a glass top, may have its prime conductor easily charged by allowing a sharp point, or a series of sharp points, to project from the back of the rubber. The free negative of the rubber is thus enabled to escape into the atmosphere, and an equal quantity of positive to enter through the points from the atmosphere, thus securing the neutral condition of the rubber which is necessary to continue the excitement of the plate.

Winter's Machine.

The Winter Machine is a modification of the Plate Machine, and was developed by Winter, of Vienna. It differs from it in having only one pair of rubbers instead of two, and the prime conductor spherical in form instead of cylindrical. To this spherical conductor two rings are attached which are placed on each side of the plate. The portion of the rings towards the plate is grooved, and lined with metal, from which a series of points extend towards the plate, which assist in charging the prime conductor as in the other cases, or a ring of thin metal is fixed in the middle of the groove, and has its edge turned towards the plate. A ring, having a diameter of 3 or 4 feet, is sometimes fixed

FIG. 50.



Winter's Machine.

into the top of the sphere to increase the surface of the prime conductor (fig. 50). This enables much longer sparks to be obtained from this machine than from the ordinary ones. The exterior of the ring is of polished mahogany, which covers a very stout brass wire. It is necessary that the ring and its connection should be perfectly smooth in all its parts, otherwise the electricity will escape, and the tension become rapidly reduced.

This machine is charged similarly to the others, and like them may be charged either positively or negatively by connecting the rubber or the conductor with the earth, and insulating the part required to be charged.

Theories of Charging the Prime Conductor.

The theory which has been given to account for the charging of the prime conductor of the Electrical Machine is what is termed '*The Addition and Subtraction Theory*,' and is the most satisfactory explanation if the '*Two Fluid Theory*' of electricity be adopted. Two other theories have been advanced, both of which are worthy of attention, they are :—

a. The Addition Theory.
b. The Subtraction Theory.

a. **The Addition Theory** supposes that the excess of positive, which charges the prime conductor, is due to the passage of electricity from the cylinder or plate through the points to the conductor. It thus receives more electricity than it would have in its neutral condition; and is said to be positively charged. This explanation is most consistent with the 'One Fluid Theory' of electricity.

b. **The Subtraction Theory.**—The subtraction theory assumes, that, when the positively excited cylinder or plate approaches the prime conductor, it acts upon it inductively, attracting the negative, but repelling the positive. The position of the points, facing the cylinder or plate, permits the rapid and continuous discharge of negative electricity from the prime conductor to the excited glass. This is sufficient in quantity to neutralise it. The positive electricity, remaining in the prime conductor, as the negative is being withdrawn, increases in tension, until it becomes so great as to interchange with the adjacent atmosphere, and so maintain the conductor uniformly charged. The supporters of this theory contend that no positive enters the prime conductor, but that it is entirely charged by the withdrawal of the negative through the points. The conductor would thus be always positive, and the rake turned towards the glass negative.

Experiments with the Electrical Machine.

Well warm and wipe the machine with a clean warm duster before use. Connect the rubber with the earth, and, after having regulated the pressure of the rubber against the cylinder or plate, turn the handle. Bring the knuckle of the finger to the prime conductor of the machine —notice spark. This is long, sharp, and stinging, when the weather is dry and frosty; but feeble when the air is damp.

Hold a brass rod terminating in a knob to the charged prime conductor, better sparks are produced. Present a point towards it, and no spark will be noticeable.

Fix Henley's Quadrant Electrometer to the prime conductor; notice rise of pith-ball, as the machine is turned. Take spark from prime conductor with knuckle or knob at the end of brass rod, the pith-ball falls. Present a point to prime conductor, and turn machine, the pith-ball remains at rest; remove the point away from the influence of the conductor, the pith-ball rises; bring the point again towards it, the ball immediately falls.

Charge the prime conductor, and notice the height to which the pith-ball rises. Cease turning the machine, and mark the gradual fall of the pith-ball, without any visible influence affecting it. The quickness of the fall indicates the invisible influences which are tending to reduce the tension of the prime conductor.

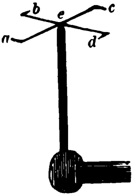
Make a tassel of tissue paper, and fasten it to short rod of deal; attach it to the prime conductor, the strips will repel one another, as the prime conductor becomes charged. Hold a pointed metallic rod in the hand, cover the point with the fore-finger, and present it to repelled strips—notice effect; remove the finger—contrast result. A head of hair is sometimes used in a similar way.

Attach a point to prime conductor, and turn the machine : no spark can be obtained. Fix Electrometer on prime conductor, there will be no rise of the pith-ball, while the point is attached. Fasten tassel as before, there will be little or no repulsion of the strips. This arises from the reduction of the tension of the electricity of the prime conductor by the rapid interchange of electricity through the point.

Various other experiments may be performed with the Electrical Machine, if the necessary apparatus be at hand such as :—

The Electrical Whirl.—This consists of an arrangement similar to that represented in the diagram fig. 51. Four pieces of brass wire are bent at right angles, and, terminating at *a*, *b*, *c*, *d*, in sharp points, are fixed at right angles to one another in a circular piece of brass, *e*. This central portion has a hole in the middle of its lower face to rest on a pivot, that it may move with the slightest amount of friction. The support for this whirl is a short brass rod, ending in a sharp point. On turning the machine the whirl rotates in a direction opposite to that to which the points are turned. The speed of rotation is greatest when the tension is highest, and least when it is lowest.

FIG. 51.

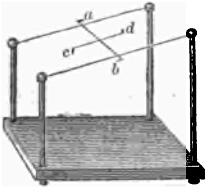


Electric Whirl.

Electrical Inclined Plane.—Another striking experiment to illustrate the effect of points is afforded by what is known as the Electrical Inclined Plane.

A rectangular wooden base has four glass rods fixed into it, two at the front, and two at the back. The front rods are shorter than the back ones, as represented in the diagram fig. 52. To the top of each rod a brass ball is attached, and two parallel wires, fastened to the knobs, extend from each front to each back rod. Two thin wires, *a*, *b*, *c*, *d*, cross each other at right angles, and the ends are also bent at right angles, and terminate in sharp points. The points *a* and *b* are horizontal, but face in opposite directions ; while *c* and *d* are vertical and point respectively upwards and downwards. On connecting the arrangement with the electrical machine by means of a wire or chain, attached to one of the knobs, and charging the prime conductor, the wires become charged, and the electricity escaping through the points causes the wire *c d* to rotate on *a b* as an axis, and *a b* at the same time to roll up the inclined plane.

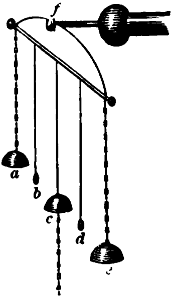
FIG. 52.



Electric Inclined Plane.

The Electrical Chimes.—This forms a pleasing experiment, and is based upon the principle of electrical attraction and repulsion. Two small brass bells *a* and *e* are hung by small chains, and two small hollow brass balls *b* and *d*, and another similar bell *c*, are suspended by silk strings. The bell *c* is also connected with the earth by means of a wire or chain. The whole arrangement is hung from the prime conductor of an electrical machine by the hook *f*, fig. 53. On turning the machine, *a* and *e* become positively charged, and attract *b* and *d*. These are charged positively on touching *a* and *e*, and are consequently repelled to *c*. On touching *c* they become neutralised, and are again attracted to *a* and *e*. This attraction and repulsion cause the balls to oscillate, sometimes very rapidly, between *a* and *c*, and *c* and *e*. The force with which the balls strike the bells produces a sound sufficiently loud to be distinctly audible; so that they form a simple set of Electrical Chimes.

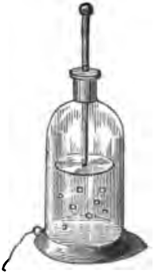
FIG. 53.



Electrical Chimes.

Electrical Hail.—The force of attraction and repulsion may again be well illustrated by what is known as the Electrical Hail. A glass vessel, having a brass top and wooden bottom, which has been coated with tin foil with a loop attached for earth connection, has a brass rod entering it from the top. This rod terminates outside the vessel in a small brass knob, but inside in a brass disc (fig. 54). The distance between the disc and the bottom is adjustable. In this vessel between the disc and bottom is placed a number of pith-balls. The knob is then brought into contact with the prime conductor of the machine, and positive electricity accumulates on the disc. This attracts the neutral pith-balls. They are immediately charged by contact with the disc, and instantly repelled. When they touch the tin-foil-covered wooden bottom, they are again neutralised, and attracted towards the disc. These changes take place rapidly and continually, while the machine is being charged, and the pith-balls, as they are attracted and repelled, resemble the falling of hail.

FIG. 54.

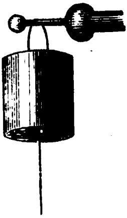


Electrical Hail

Dancing Figures.—Sometimes two discs are used, one of which is hung from the prime conductor, and the other supported on a stand, which is in earth contact. Pith figures are placed on the lower disc, and they dance up and down, as the machine is turned. These movements are explained in the same way as the pith-ball movements in the previous experiment. The figures may also be used in the same glass vessel as the pith-balls are placed in.

Electrified Water.—To perform this experiment a small brass bucket is used, which has a tiny hole in the bottom. The bucket is partly filled with water, which drips drop by drop from the small hole beneath. On hanging it to the prime conductor of the machine and charging it, the drops succeed each other so rapidly from the repulsion which takes place between them, because they are charged with similar electricity, that they appear to flow in a continuous stream. Another very striking experiment to illustrate the mutual repulsion of the particles of a body may be shown in the following manner. Fill a small glass funnel, having an opening in the stem about $\frac{1}{8}$th of an inch in diameter, with fine silver sand. If the sand be not electrified, it will fall to the ground in a continuous straigth stream; but, if a wire or chain be brought from the prime conductor into the sand, as soon as the machine is turned the sand particles forming the stream fly asunder, and spread out from the repulsion which takes place between them.

FIG. 55.

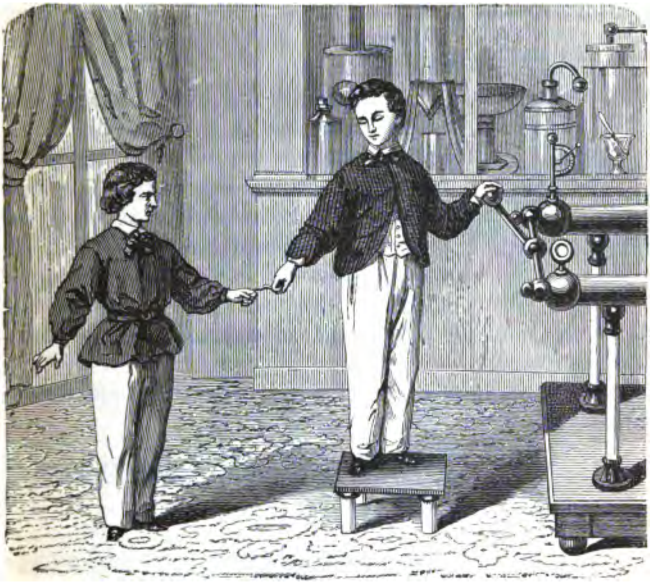


Electrified Water.

Head of Hair.—A wooden head, having long coarse hair, is attached to the prime conductor of an electrical machine by means of a brass rod. As the prime conductor becomes charged, the hair rises, and spreads out in consequence of the repulsion, which takes place between the separate hairs, because they are charged with the same kind of electricity. A tassel made of tissue paper, and fastened to a rod of wood, or to a thick brass wire, is sometimes used to illustrate the same principle.

The Human Body Insulated.—A lad standing on an insulating stool, either holding the prime conductor by the hand, or connected with it by means of a wire or chain, is for the time being, as it were, a portion of it, and all the phenomena exhibited by the charged prime conductor may be also obtained from the insulated charged person. Sparks may be drawn from parts of his body, conductors may be charged from him, and bodies in different electrical conditions may be attracted in some cases, and repelled in others; and if another person, standing on the ground, holds his hand over the head of the charged person, the hair will immediately rise towards the hand. If a brass rod, terminated in a knob, be held close to a gas-jet, through which the gas is escaping, the gas may be lit by means of the discharge from the human body.

FIG. 56.



Spark from Human Body.

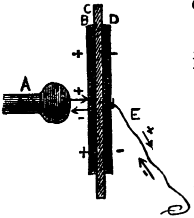
10. The Leyden Jar and similar arrangements.

Under this division of the subject we shall deal with what is known as the condensation ot electricity. This is effected by using two thin metal or metallic plates, as plates of brass, or tin-foil, which are separated by some insulating substance, generally glass coated with shellac varnish, but sometimes ebonite, or gutta-percha is used. One of these plates is brought near to, or into contact with, the prime conductor of the electrical machine, while the other is put into earth connection.

By this arrangement the electricity on the plate near the prime conductor can receive a far higher charge of electricity than it could have received without the presence of the second earth-connected plate.

The accompanying diagram will explain the relation of the parts of the condenser to each other, and its position with regard to the prime conductor of the electical machine.

FIG. 57.



Electrical Condenser.

A represents the prime conductor, B is the collecting or accumulating plate, and D the condensing plate, for it is from its action that electricity of a higher tension is accumulated on B. C is the insulating substance, separating the two metal plates. This is usually termed the dielectric, because the electricities act upon one another through its substance. E is the earth-connecting wire.

The three most common forms of electrical condensers are :—

a. Epinus's Condenser.
b. Franklin's Pane.
c. The Leyden Jar.

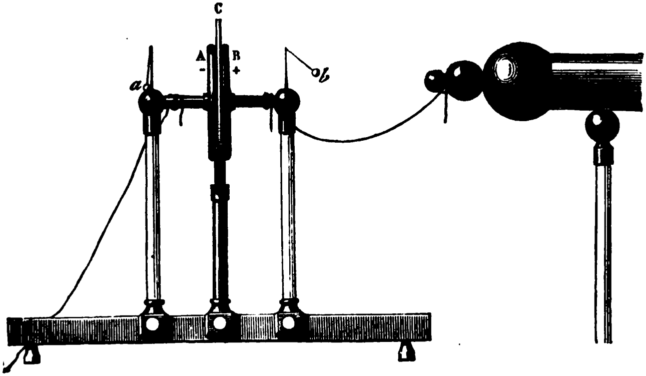
a. **Epinus's Condenser.**

This consists of two brass discs, separated by a dielectric, which is generally glass coated with shellac varnish. The discs are fastened to brass rods, which terminate in glass handles for adjustment. These brass rods are supported by rods of glass, which terminate in a brass cap, furnished with a suitable arrangement for the brass rods to move freely through, so that they may be brought near to or withdrawn from the dielectric.

Method of charging.—The two plates are brought close to, and on either side of, the dielectric, and the strongest charges are obtained when the plates are as near as they can be brought to it.

When suitably arranged, one plate is brought within striking distance of, or connected by a wire or chain with, the prime conductor of the electrical machine, and the other is connected with the earth. As the machine is turned, the collecting plate becomes positively charged, and the condensing plate negatively. The collecting plate is positively charged from the prime conductor by its attracting some of the negative from the disc, and communicating an equal quantity of positive to it. This positive charge, acting through the dielectric, decomposes the electricity of the condensing plate, attracts the negative, but repels the positive. The repelled positive passes to the earth through the wire, while an equal quantity of negative is attracted from the earth to the condensing plate. This accumulated negative reacts through the dielectric on the opposite disc attracting the positive but repelling more of the negative. The tension of the two electricities is thus greatly increased, and they are consequently drawn strongly towards one another through the substance of the dielectric.

FIG. 58.



Epinus's Condenser.

If this material be too thin, or not uniform in its character throughout, the two electricities sometimes pierce the dielectric, and thus neutralise one another, producing what is termed a *disruptive discharge*, and thus spoiling the arrangement.

At other times the electricities acquire such density and tension at the edges of the discs, that they recombine over the top, bottom, or sides of the dielectric sheet according to the easiest passage afforded them. This forms what is known as the *spontaneous discharge.* Both of these are irregular discharges.

Methods of discharging. The two methods of discharging are :—

a. The slow discharge.

b. The instantaneous discharge.

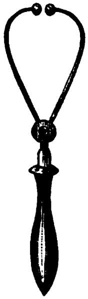
a. The slow discharge is produced by touching the collecting plate with some conducting substance, and removing the small amount of free positive, which is always found there, when the condenser is charged. The removal of this free positive liberates a certain amount of negative from the condensing plate. This may also be removed by touching that plate with the finger, or some other good conductor. The withdrawal of this again liberates a small quantity of positive from the first plate, and thus regularly, and gradually, this alternate discharge proceeds, until, after a very large number of discharges have been taken from each in succession, the discs become thoroughly neutralised.

This discharge from one plate, and simultaneous liberation of electricity from the other, may be exhibited by attaching small quadrant electrometers to the supports, which are in metallic connection with the discs ; the fall of the pith-ball in one case indicates the withdrawal from one, while the rise of the opposite electrometer exhibits the liberation of electricity from the other plate.

b. The instantaneous discharge takes place when both discs are connected by some conductor, or when a conductor, which is in contact with the condensing plate is brought near enough to the collecting plate to permit of the electricities piercing the air space between the plate and the conductor. The recombination of the two electricities is announced by a sharp crack, and a more or less brilliant spark.

The Discharging Rod.—The apparatus, which is generally used for discharging condensers, is known by the name of the discharging rod; and is represented in diagram, fig. 59.

FIG. 59.



Discharging Rod.

It consists of two equal pieces of bent brass wire, connected by a hinge. At the end of each piece of wire is a small brass knob; and this arrangement is fastened by means of a brass cap to a glass handle for the purpose of insulation. When one knob is brought into contact with the condensing plate, and the other near enough to the collecting plate, a spark is seen, and a report is heard, which is more brilliant and louder as the tension of the electricity accumulated on the discs is greater. These phenomena arise from the recombination of the two electricities of the discs through the conducting medium provided by the wire. The condenser may be also instantaneously discharged by connecting the two discs with the two hands in a similar manner to that adopted with the discharging rod, first touching the condensing plate, and while one hand rests on it, bringing the other to the collecting plate. The discharge then takes place through the operator's body, and a shock feeble or severe is felt according to the size of the condenser, and the tension of the charge. Several persons may experience this shock simultaneously if they hold each other's hand tightly, and the person at each end of the chain touch the plates in the order previously described. The heavier the charge is, the more severe will be the shock. Three things affect the strength of the charge of a condenser: (1) the size of the plates; (2) the substance of the dielectric; (3) the nearness of the plates.

Large plates enable a greater quantity of electricity to be decomposed and condensed than small ones. The charge is higher for equal thicknesses of dielectrics according to the following order, air, resin, glass, sulphur, shellac, india-rubber, gutta-percha.

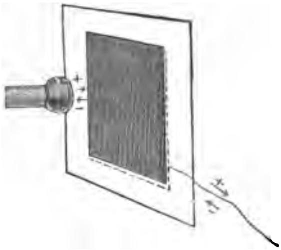
As this condensation of electricity is due to the inductive action which takes place through the substance of the dielectric, that, which permits the electricity to act most readily through it, is considered to have the *highest specific inductive capacity.*

b. Franklin's Plate or Pane.

This is the *simplest form of electrical condenser*, and consists of a thin sheet of glass coated on each side with tin-foil. The foil should not reach the edge of the glass by about two inches, and the uncovered surface should be coated with shellac varnish to prevent any escape of electricity by means of the dewy deposit which frequently forms on the uncoated glass. This arrangement is also known by the name of the *Fulminating Pane.*

Method of charging the pane.—To charge Franklin's pane the hand must support one sheet of tin-foil, while the other foil is presented to the prime conductor of the electrical machine. The arrangement then assumes the form of the condenser—the tin-foil resting on the hand becoming the condensing plate, and the sheet presented to the prime conductor the collecting plate. The charge is accumulated in a similar manner to that on the condenser, the collecting plate is charged positively and the condensing plate negatively. It may also be charged by connecting the outer coating with the earth by a wire or chain, and bringing the collecting plate to the prime conductor.

Fig. 60.



Franklin's Pane.

Discharging the Pane.—The pane may be discharged like the condenser, either slowly or instantaneously, by similar means, in like manner, and with the same results, viz., the spark, crack, or shock to the human body.

A common and amusing experiment is to place a coin on the collecting plate of the charged pane. A person should support the pane, by resting the condensing plate on one hand, and endeavour to remove the coin with the other. A smart shock will then be communicated to the operator arising from the recombination of the two electricities.

Experiments.—Bring discs close to dielectric, connect collecting plate by means of chain or wire to prime conductor, or bring it within sparking distance of machine. Connect condensing plate with earth by touching it with the hand, or bringing wire from it to the earth. Turn machine, and the condenser becomes charged. Remove earth connection with hand, and connection with machine by means of some insulating substance. Bring one knob of discharging rod first to condensing plate, let it remain in contact with it, bring other knob very near to collecting plate. Notice discharge, spark, and report.

Charge again similarly, bring one hand into contact with each disc; the discharge now consists of spark, report, and shock.

Let several persons join hands. Charge condenser again. The persons at the ends should touch the discs in the following order, one the condensing plate, and the other the collecting plate; the shock attending the discharge will pass through every individual if the chain be unbroken.

If possible fix two small electric pendulums to condenser, and notice rise of pith-balls alternately as free electricity is liberated.

Charge condenser, insulate it, and discharge it slowly by touching alternately, first the collecting and then the condensing plate. Feeble sparks and reports will be seen and heard at each discharge. Charge condenser highly, let it remain a short time before discharging it. Take first discharge. A second, but much more feeble discharge, may now be obtained, and then a third, and sometimes others in succession, but each succeeding one will be weaker than the one which precedes it. These are named *residual discharges.*

Fulminating Pane. Hold pane on the hand, and bring upper foil within sparking distance of the prime conductor of the machine. Charge it in this way.

Bring knob of discharging rod to condensing foil, and, while it is in contact with it, let the other knob be brought within sparking distance of the collecting foil; the pane is discharged, shown by spark and report.

Show residual discharges of pane, as in condenser.

Charge pane as at first, take shock with two hands, one on either side. Next let several persons join hands, and take the shock from the pane, when fully charged.

To show kind of Electricity on each side of pane.—Insulate pane, and attach wire to condensing foil and gold-leaf electroscope. As soon as electricity accumulates on the collecting foil, the leaves of the electroscope diverge with positive electricity. Test this by bringing first a glass rod, rubbed with silk near it, leaves still further diverge; next sealing-wax, rubbed with flannel, leaves collapse.

Obtain two sheets of tin-foil of equal sizes, and a sheet of glass about 1½ inches larger all round. Coat the glass with shellac varnish, and attach a silk handle to each end of it by sealing-wax. Bring wire earth-connected to the top of insulating stool, lay foil on wire, then glass on foil, and foil again on glass. Connect upper surface with machine by means of chain or wire, pass another wire from it to electroscope.| Remove wire from machine by means of insulator, lift up glass plate gently by silk handles, the leaves of the electroscope diverge with positive electricity.

Charge pane, test free electricity of collecting plate by bringing it to electroscope. Discharge this, then test free electricity of condensing plate.

Another experiment consists in pasting both the foils on the glass. Fasten a tongue from the lower round the edge of the glass. The upper foil has also a long tongue, which is wrapped round a varnished glass rod.

By rolling the rod to and fro the distance between the upper and lower foils is made lesser or greater, and on working the machine the spark increases in brilliancy and loudness, as one foil is at a greater distance from the other.

c. The Leyden Jar.

The most important and useful form of the electrical condenser is what is known as the Leyden Jar. It was so named because the principles of its action were first determined by the philosophers of Leyden, a city in Holland.

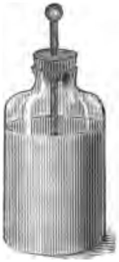
In a rude form it was first discovered by Kleist, a German clergyman, A.D. 1745; but its present construction is due to Dr. Watson.

He was the first to coat the jar inside and outside with silver-foil. The earliest jar was partly filled with water, and held in the hand, a nail passed into the water and projected beyond the cork. This was presented to the prime conductor of the electrical machine, and an interchange of electricities took place, between the inside and the prime conductor, and the outside and the earth, and thus the jar was charged.

Construction of the Leyden Jar.

The present Leyden jar consists of a wide-mouthed glass jar or bottle, coated inside and outside with tin-foil to about two inches from its neck. The mouth of the jar is closed by a piece of dried wood or a large cork, through which passes a brass rod, which must either rest on the inner coating, or be brought into contact with it by means of a piece of wire or chain attached to the rod. The rod must be insulated from the cork, and the end outside the jar terminate in a knob, otherwise there will be a tendency for the charge to escape into the air through the pointed end. It is also advisable to give the cork or wood and the uncovered neck of the jar a coating of shellac varnish for the purpose of better insulation. The inside coating of the jar is generally used for the collecting plate, and the outside surface for the condensing one. Under these conditions the jar would be charged positively; but, if the outer coating be used as the collecting plate, and the inside as the condensing plate, the jar will be charged negatively.

FIG. 61.



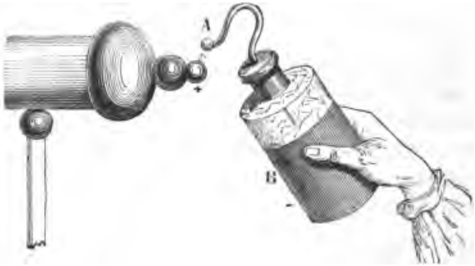
Leyden Jar.

The jar is considered to be charged with the kind of electricity which is accumulated on the inside coating.

Method of charging the Leyden Jar.

a. Positively.—To charge the jar positively, hold the outer coating in the hand, or place it in conducting connection with the earth by means of a wire or chain, so that there may be an easy means afforded for the electricities to pass to and from the earth. The knob must then be brought either into contact, into conducting connection, or within sparking distance of the prime conductor of the electrical machine. As the machine is turned, positive electricity leaves the prime conductor and passes into the jar, while an equal quantity of negative passes from the jar to the prime conductor. This causes a rapid accumulation of positive electricity on the inner surface of the jar, which acts inductively through the dielectric, attracting the negative electricity of the outer coating, but repelling the positive. This repelled positive interchanges with an equal quantity of negative from the earth, and thus the negative charge of the outer coating is considerably strengthened. This outer charge of negative electricity reacts through the dielectric on the inner coating, and by attracting the positive more strongly, and liberating more negative, causes the positive charge accumulated on the inside of the jar to acquire much higher tension than the electricity of the prime conductor, from which the charge is obtained. A thin glass jar can receive a higher charge than a thicker one of equal size. When, however, the glass is very thin, the jar is liable to be pierced, if it be not of uniform character

FIG. 62.



Charging the Leyden Jar.

throughout, by the opposite electricities penetrating the dielectric, and producing what is known as a *disruptive discharge*, which spoils the jar.

The repulsion of positive from, and attraction of negative to, the outer coating, as positive electricity accumulates inside the jar, may be exhibited by several simple experiments:—

If the jar be placed on some insulating substance, and a wire be attached to a gold-leaf electroscope, the leaves instantly diverge, as electricity interchanges between the machine and jar.

Again, a lad standing on an insulating stool, and holding the outer coating in his hand, can attract and repel the pith-ball of the electric pendulum; by holding his hand over the disc or ball of the electroscope, he can cause the leaves to diverge, and if necessary charge it; by presenting his hand near a well-balanced lath which is free to move horizontally, he can, by attracting it, draw it round; and by bringing his knuckle near another person, a spark will be seen to pass between them. If a wire attached to a jar similarly insulated be connected to one disc of Epinus's condenser, and the other disc be connected with the earth, the condenser may be charged, and a series of Leyden jars may be similarly charged when suitably connected as in the cascade arrangement (see p. 77).

b. Negatively.—If the knob be held in the hand, or otherwise put into conducting earth connection, and the outer coating be brought into contact with, or within sparking distance of, the charged prime conductor of an electrical machine, in a similar manner to that previously described, positive electricity of high tension accumulates on the outside, and negative on the inside. The jar is thus charged negatively.

Other results.—It is generally stated that an insulated jar cannot be charged, but this should be modified to some extent; for the character of the insulation affects the amount of the charge capable of being accumulated in the jar. If the jar be hung from the knob by a silk thread the insulation is most perfect, and the indisposition to receive a charge is most complete. When it stands on an insulating stool, a feeble charge may be imparted to the jar; for the neutral electricity of the wood of the top of the stool will enable a certain interchange of electricities, and, consequently, a certain amount of positive and negative to become bound on the interior and exterior coatings of the jar; and thus a slight charge is produced. A feeble charge, which under certain conditions may be strengthened, is communicated, if the jar, while being charged, rest on a sheet of ebonite, resin, or other insulating substance. The repelled positive of the outer coating acts through the insulating sheet, and attracts negative from the earth to the other side of it. This produces a similar arrangement to the Leyden jar, or forms with the jar a kind of compound condenser. From this cause the jar may be charged with electricity of a certain low tension. In a short time, however, the tension of the repelled positive of the outer coating, and the attracted negative from the earth becomes so high, that a long spark is perceived to pass across the surface of the insulating sheet. This discharge enables the jar to become more highly charged than it otherwise would be.

No charge can be communicated if both the inner and outer coatings be in conducting earth-connection; as under these circumstances the positive electricity from the prime conductor interchanges with an equal quantity of negative from the earth by means of the connection with the inner coating without at all affecting the outer coating.

To discharge the Leyden Jar.

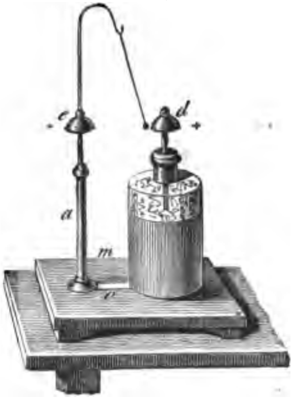
This may also be done, as was the case with Epinus's condenser, either slowly or instantaneously.

a. Slowly.—To discharge the jar slowly it should be placed on an insulating stool, or some insulating substance, and be touched alternately commencing with the knob, which is in contact with the inner coating. A little of the free positive is thus removed from the inside of the jar; this liberates a little negative from the outside, which is also free, and may be removed by touching it with the hand, or any conductor in earth-connection. The removal of this sets free another small quantity of positive from the inside coating, which on being discharged, liberates negative again from the outer coating. These alternating results take place at each discharge of inner and outer coating, until, after a considerable number of discharges have been taken, the whole charge of the jar is neutralised.

The slow discharge may be made an interesting experiment, as shown in the accompanying diagram, fig. 63.

Two bells, *d* and *e*, are arranged on the same level, one being fixed at the top of the Leyden jar, and the other on the stand of an electric pendulum, which is in metallic connection with the outer coating of the jar. The ball is a light copper one, and is suspended by a fibre of silk.

Fig. 63.

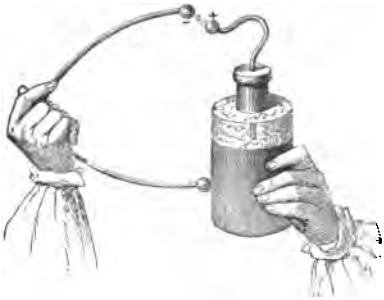


Experiment showing Slow Discharge of Leyden Jar.

When the jar is sufficiently charged, and brought at a suitable distance from the insulated ball, the free electricity of the inner coating attracts the copper ball, which strikes the bell and produces a ringing sound. The ball is instantly charged and repelled, but it is then attracted by the negative bell on the stand of the pendulum. This it strikes, producing another ring; but at the same instant the ball is neutralised and charged negatively by the contact, and repelled to the bell attached to the inner coating of the jar. This again charges and repels it; and similar results follow, over and over again, until the jar is completely discharged. During this discharge the bells ring from the ball striking them alternately as long as the interchange takes place. This experiment is most successful when the jar is large and the air dry.

b. Instantaneously.—The instantaneous discharge may be produced either by using the discharging rod, or by connecting the outer and inner coating by the two hands. In the former case a similar plan must be adopted to that used with the condenser, viz., the outer or condensing surface must first be touched with one end of the rod, and, while one knob is in contact with this, the other must be brought near to the knob of the jar. A *brilliant spark and sharp report*, if the charge be high, announce the recombination of the two electricities, and what is known as *the discharge of the jar*.

FIG. 64.



Discharge of Leyden Jar.

Should the jar be discharged by connecting the two coatings with the hands of a person, the outer coating should be first touched, as before described; and then the knuckle of the finger be presented to the knob. The spark and report are also heard in this case, but at the same instant a shock more or less severe is felt by the experimenter. A strong discharge may be felt by several persons simultaneously, providing they hold each other's hands tightly, and the person at one end of the chain touches the outer coating, while the one at the other end presents his or her knuckle to the knob.

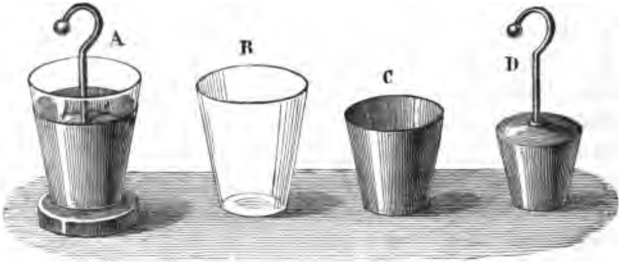
Residual Charge.—If a Leyden jar be highly charged, and allowed to remain for a short time before it is discharged, a second discharge may be obtained from it, and sometimes others, each succeeding one being weaker than the preceding. These form what are known as *residual discharges.* The explanation of these discharges is the following :—As a jar receives its charge, the two electricities attract one another through the glass ; this causes the opposite electricities to be dragged towards each other some little distance into the substance of the glass. During the first discharge all the opposing electricities do not recombine—by far the largest portions do—but that which had penetrated into the substance of the glass requires a little time to ooze out again, and spread over the metallic surfaces of the foil. When this has taken place another discharge may be obtained ; but it is much weaker than the first. If the jar be allowed to remain for another short time, a third discharge is noticeable, and sometimes others.

Similar residual discharges are apparent in each form of the condenser, and are due to the same cause.

Should the glass of the condenser be not of the same thickness throughout, it is sometimes pierced from the force of this attraction. A very highly charged jar, if allowed to stand for some time after it has received its charge, will be liable to the same kind of accident.

The two electricities which are bound when a Leyden jar is charged are supposed to be held on either side of the glass, and not to remain on the metallic surfaces connected with it. This idea is supported by an experiment, which is easily performed. For this purpose the jar must be so constructed that the parts may be separated from one another. The diagram (fig. 65) exhibits the arrangement. C is a tin outer covering or condensing plate, B is the glass corresponding to the jar or phial of the ordinary Leyden jar ; D is the inner coating, made of tin, and forms the collecting plate, the brass rod terminating in a knob, being in conducting connection with the inner coating. The apparatus in its complete form is represented by A.

FIG. 65.



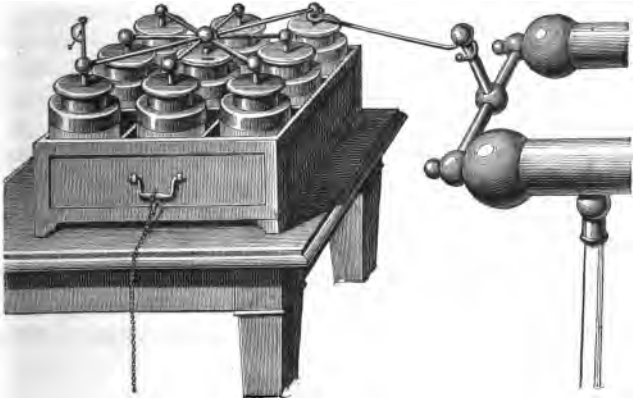
Leyden Jar with movable coatings.

The method of charging is similar to that of the ordinary jar. When charged, it should be placed on an insulating stool, or a sheet of ebonite or vulcanite, or on some insulating substance, and the inner coating should be removed by means of an insulating rod, or the fingers protected by indiarubber tubes. A stick of sealing-wax or rod of ebonite will do well for this. The glass may then be removed with the unprotected fingers. When the parts are thus separated each coating may be discharged, and the discharging rod brought to the two sides of the glass in a similar manner to the method of producing the instantaneous discharge of the Leyden jar.

On restoring the parts to their former positions, a brilliant spark will be obtained from the arrangement, when the outer and inner coatings are connected by the discharging rod or other conductor. To secure the success of this experiment care must be taken in reconstructing the jar. The outer coating should first be placed on some insulating substance, the glass next lifted into it with the unprotected hand, and the inner coating finally restored by the help of the same insulating rod.

Leyden Batteries.—A Leyden jar can only receive a certain definite amount of charge, dependent on its size, the thickness of the glass, and the extent of the coated surface. Other things being alike, the charge is always strongest when the glass is thin. A larger jar of similar thickness to a smaller one will also receive a greater charge than the smaller one. Hence powerful charges may be obtained from large and thin jars; but these are expensive, and very liable to be pierced by the discharge of the two electricities through the thin glass; thus spoiling the jars for further use. They are, therefore, not generally used for experimental purposes. Instead of large jars, a number of small ones are connected together to produce these powerful effects. Such an arrangement is called a Leyden battery.

FIG. 66.



Ordinary form of Leyden Battery.

Leyden batteries are of two kinds:—

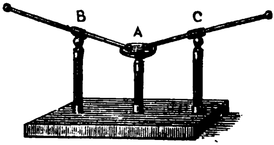
a. The Ordinary Form.
b. The Cascade Arrangement.

a. The Ordinary Form.—The ordinary form of the Leyden battery consists of several jars, so arranged that their outer and inner coatings may be connected in such a manner, that the outer coatings may form one continuous outer surface, and the inner coatings a continuous inner one. This is secured by placing all the jars in a box, which is lined with tin-foil, on which the outer coatings of the jars rest. The inner coatings are connected by means of brass rods joining the knobs together. The external tin-foil is connected with the handles of the box, and to one handle a chain is attached to secure the necessary earth-contact.

Charging and discharging.—To charge this combination the inner coating must be connected with the prime conductor of the electrical machine by means of a chain or wire, and the chain attached to the handle of the box must be brought into perfect earth-contact. On turning the machine the electricity is accumulated on the jars in a similar manner to the single jar, described in p. 68. Several turns are required before the battery becomes charged with high tension electricity, and the larger and more numerous the jars are, the longer time is required to charge the arrangement, and the more powerful is the accumulated electricity stored in them. The force of the charge of such a battery is equal to that of a large jar, whose inner and outer coatings are equal to the sum of the inner and outer coatings of the jars composing the battery. It is also equal to as many times the charge of a single jar, as there are equal jars connected together to form the battery.

The Universal Discharger.—To discharge a Leyden battery an apparatus named the Universal Discharger is required. Its construction will be understood from the accompanying diagram (fig. 67). A is a small ivory or ebonite table, B and C are two movable brass rods terminating in knobs, which are fastened to universal joints, and these supported on glass legs. When a battery is to be discharged, the knobs are brought within striking distance above the table. One rod is con-

FIG. 67.



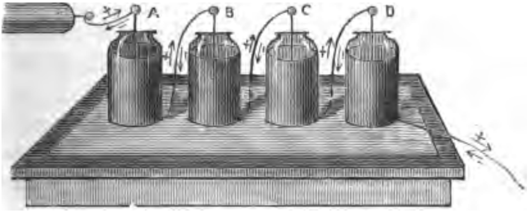
Universal Discharger.

nected by means of a chain or wire with the handle of the box, and is thus in contact with the outer coating of the jars, while the other rod is connected similarly with one end of the jointed discharger. The other end of this discharging rod is brought near to, or into contact with, the inner coatings of the jars. A considerable spark is then seen to pass across the insulating table. Should any object, resting on the table between the knobs, resist the passage of the electricity from knob to knob, certain visible effects are produced, according to the nature of the resisting substance, as the electricity forces its way through it.

These are of the following character : illuminating, heating, fracturing, and sometimes magnetising effects. Thus a lump of sugar, a lemon, or an egg would be brilliantly illuminated, a thin platinum wire would be volatilised by the discharge from a powerful battery, a piece of wood struck in the direction of its fibre would be split asunder, and a steel needle across which the discharge had been sent would be magnetised. Great care is required in discharging large batteries, or serious accidents may arise if the discharge should pass through the human body.

b. The Cascade Arrangement.—The cascade battery is formed by connecting a series of Leyden jars in the following way :—The outer coating of the first jar is connected by a wire or chain with the inner coating of the second, the outer coating of the second with the inner coating of the third,

FIG. 68.



Cascade arrangement of Leyden Battery.

and so on throughout the series. The last jar must have its outer coating in earth-connection. Any arrangement of the jars which secures this result would form a cascade battery.

Charging and discharging.—By this combination a number of jars may be very nearly equally charged. On bringing the knob of A into contact with the prime conductor of a machine charged positively, it interchanges its neutral electricity with it, receiving positive, and giving up negative. In this way positive accumulates in the inside of A. This positive repels the positive from the outer coating of A, which passes to the inner coating of B. B returns an equal quantity of negative back to the outer coating of A. The charge of B acts similarly on C, and so forth, until the last jar is reached, when the repelled positive is driven to the earth, and negative drawn from it to the jar. After a series of this kind has been charged, if a conductor be brought to the outer coating of the last jar, and then to the inner coating of the first, the electricities will simply recombine and reduce the jars to the neutral condition. To secure the discharge of this arrangement the connections must be removed with some insulating substance, and the knobs connected together by a chain, or by metallic rods, so as to have all the inner coatings in connection. The outer coatings must also be in conducting connection, which may be done by placing the jars on a metal plate. In this way the combination is equivalent to a single large jar, whose coated surface would be equal to the sum of all the coated surfaces of the series of jars. To discharge this battery, place a conductor in contact with the outer coating of either of the jars, and bring the other end of it to one of the knobs. The universal discharger may be employed here for exhibiting experiments similar to those described in connection with the ordinary Leyden battery.

On charging by cascade arrangement Professor Carey Foster remarks :—‘When an electric battery is charged by cascade, each jar receives a lower charge than the one which precedes it, and a higher charge than the following one; the charge of the second jar is in fact only equal to what the first would be if the thickness of the glass were doubled; for the inductive action by which its charge is produced takes place between two thicknesses of glass instead of only one. Similarly the charge of the third jar is produced by inductive action taking place through three thicknesses of glass, and is therefore equal to what the first jar would receive if the glass were made three times as thick, and so on of the others.'

Experiments with the Leyden Jar.—Examine construction of jar and discharging rod; charge jar by contact with prime conductor, and wire or chain connection with the earth, and discharge it instantaneously. Charge again by connecting the inner coating with the prime conductor by means of a wire or chain, retaining a similar connection with the earth as in the last case, and discharge as before. Obtain another charge by holding the jar in the hand, and, bringing the knob within sparking distance of the prime conductor, again discharge. Charge jar negatively by holding knob in the hand, and bringing outer coating within sparking distance of the machine.

Show slow discharge by placing jar on some insulating substance, and touching alternately the knob and the outer coating with the hand. If possible exhibit slow discharge by bell and ball arrangement.

Discharge a charged jar instantaneously with discharging rod. Do so again by touching the outer coating and the knob with the two hands. Send charge through several persons joining hands.

Place jar on some insulating substance; attach wire to electroscope; notice divergence of leaves, as jar is being charged; remove wire connection; test kind of electricity with glass rod rubbed with silk, repulsion, positive.

Stand a lad holding outer coating of jar in hand on insulating-stool; commence charging jar; present knuckle to pith-ball of electric pendulum; notice attraction, charge, and repulsion.

Let lad bring his hand over the top of an electroscope; notice divergence of leaves with free positive test as before; touch electroscope while under induction; free positive disappears; remove earth-connection; withdraw inducing hand; the leaves diverge with negative electricity; test with sealing-wax rubbed with flannel; notice greater repulsion; similar electricity.

Balance lath, so that it may be free to move horizontally; let lad standing on an insulated stool, and holding a Leyden jar which is being charged in his hand, present the knuckle of the other hand to either end of the lath, it will be attracted, and may be drawn around.

Let another person present a knuckle to the knuckle of the lad on the stool, and a spark may be drawn from him.

If the jar stand on some insulating substance, and a wire be led to one plate of Epinus's Condenser, the other plate being sufficiently near and in suitable earth-contact, the condenser may be charged from the free positive, which is repelled from the outer coating of the jar that is being charged. Show this, and discharge the condenser.

A series of Leyden jars may be similarly charged in this way, when suitably connected, as in the cascade arrangement (see p. 77). Show this.

Experiments.—Charge Leyden battery, and discharge it, using universal discharger and discharging rod, through lump of sugar, egg, series of eggs in tube, ivory ball, and lemon—notice brilliant effect. Ignite gunpowder by battery: to do this a piece of wet string must be placed in the circuit.

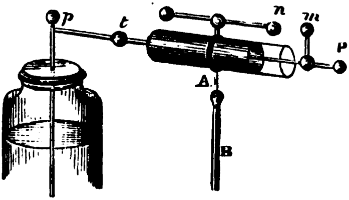
Show similar experiments with cascade arrangement.

The Unit Jar.

The unit jar is a small Leyden jar, which is useful and necessary to measure the quantity of electricity accumulated in a Leyden jar or battery. There are two common forms, Harris's Unit Jar and Lane's Electrometer. The former is placed between the prime conductor and the jar or battery to be charged, and is connected with the inner coating; but the latter is away from the prime conductor, and attached to the outer coating of it.

Harris's Unit Jar.—This consists of a glass tube, closed at one end, about 6 in. long and $\frac{3}{4}$ in. in diameter. Like the ordinary Leyden jar it has metallic surfaces inside and out to within a short distance from the top of the tube. This portion is coated with shellac varnish. Besides the knob at the end of the rod connected with the inner coating, it is furnished with another knob shown by *m* in diagram (fig. 69). This is attached by means of a metal rod and metallic ring to the outer coating of the jar; and the ring is arranged that it may slide up and down over the outer coating. In this way the distance between the two knobs *n* and *m* may be varied. The whole arrangement is supported on an insulating stem, B.

Fig. 69.



Harris's Unit Jar.

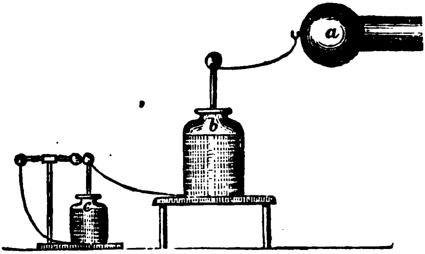
When this unit jar is to be used the two knobs *n* and *m* are brought near each other, and the outer coating is connected with the jar or battery to be charged. The knob P, connected with the inner coating, is now brought near to, or into contact with, the prime conductor of an electrical machine. On working the machine the unit jar receives its charge, which is quickly announced by the passage of a spark between *m* and *n*. This intimates that one unit charge has passed into the Leyden jar attached to it. A second spark would show that a second similar charge had been communicated, and so forth. The number of separate sparks correspond to the number of distinct charges, accumulated in the jar or battery. So that, if we required to charge a series of Leyden jars or batteries similarly, we could do so by counting an equal number of sparks from the unit jar.

The charging of the Leyden jar by this means is on the same principle as charging by cascade arrangement.

Lane's Electrometer.

This is a small Leyden jar similar to that represented in diagram fig. 70. It is furnished with an insulating stem, surmounted with a brass cap. A brass rod, terminated at one end in a knob and at the other in a metallic ring, moves freely through this. The knob attached to the brass rod faces the knob of the inner coating of the Leyden jar ; and, as the brass rod is movable through its support, the knobs may be easily adjusted as to their distance from one another. The outer coating of the unit jar must be in metallic connection by means of a wire or chain with the brass rod, and this coating should be also in good earth-connection.

FIG. 70.



Lane's Unit Jar or Electrometer.

Before charging the Leyden jar it should be placed upon an insulating stool, and its outer coating put in conducting connection with the inner coating of the unit jar. By the cascade principle the charging of the Leyden jar also charges the unit jar, and, when the quantity of electricity accumulated in the unit jar is sufficient, a spark is seen to pass between the two knobs. This serves as the unit of measurement for the quantity of electricity in the Leyden jar. A second spark announces that double the charge has been received by the Leyden jar, and so on ; n sparks showing that n times the quantity had been accumulated. If from this arrangement a certain definite charge is required for a jar or battery the number of sparks must be counted from the unit jar, and, when these are equal, equal charges will have been communicated.

The Condensing Electroscope.

The condensing electroscope, by means of a combination of the principles of the electroscope and the electrical condenser, renders small and very delicate charges of electricity visible. In the electroscope portion of the apparatus the brass rod connected with the gold leaves has a large brass disc attached to it instead of a brass knob. Another disc of the same size is fastened to an insulating handle, so as to be placed upon, or removed from the other, as desired. The faces of the discs, which are to be brought into contact, are coated with shellac varnish, which serves as an insulator, and acts the part of the dielectric, as in the ordinary condenser.

FIG. 71.

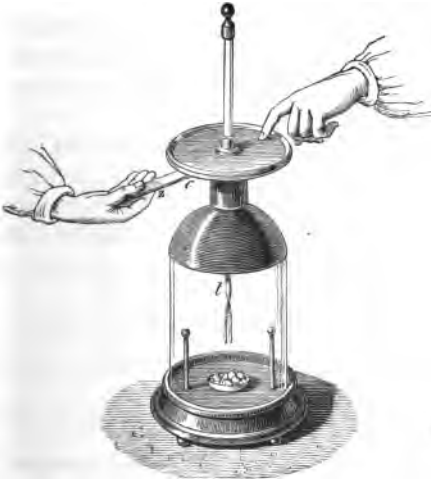
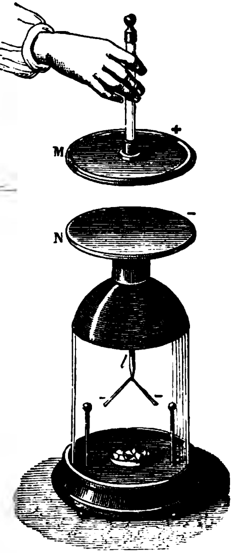


FIG. 72.



Condensing Electroscope.

The plate attached to the electroscope is the one which is touched by the body to be tested, and is named the *col-*

lecting plate, while the other, which is brought upon it, is the *condensing plate*. When the body is brought into contact with the collecting plate, the condensing plate is touched with the finger, or otherwise connected with the earth, the similar electricity is thus repelled, and the opposite attracted. On removing the finger, and then the charged body, the two opposite electricities of the collecting and condensing plates hold one another bound by their action upon each other through the substance of the dielectric, and the leaves of the electroscope are unaffected. When the condensing plate is removed by means of the insulating handle, the leaves of the electroscope immediately diverge, from the free electricity which has been liberated from the collecting plate by the withdrawal of the opposite electricity of the condensing plate.

Sometimes two metal rods terminated in knobs form part of the apparatus. These still further increase the delicacy of the arrangement, as the portions of the knobs turned towards the gold leaves become charged by induction with opposite electricities, and these will tend to produce a further divergence of the leaves.

This apparatus was first constructed and used by Volta.

Experiments.—Show both forms of unit jar if possible, and test their use.

Charge two jars with same number of sparks, and compare strength of charge by intensity of discharge.

Exhibit and explain parts of condensing electroscope—test lightly charged bodies, as insulated metal rod, or small proof plane, when brought into contact with a charged body.

11. Distribution of Electricity on Conductors.

When a conductor is charged with electricity, *the charge is distributed on the surface of the conductor*, and its arrangement depends upon the shape of the conductor on which it is accumulated. To exhibit this, conductors of different shapes must be insulated, by being placed on insulating supports, as glass rods coated with shellac varnish, gutta-percha rods, sealing-wax rods, &c., or hung by silk strings.

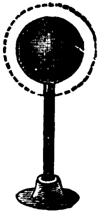
The following bodies have been most thoroughly tested: the sphere, the cylinder, the ellipsoid, the disc, and the cube. This testing may be done in two ways.

1. By bringing a proof plane into contact with different parts of the body, and then noting the strength of its charge by means of a delicate electroscope.

2. By bringing the pith-ball of the electric pendulum charged with similar electricity near the charged body. It will then be seen to be repelled to different distances from different parts of the body, and will appear to be floating in a layer of electricity of varying depth or density.

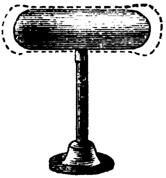
If we examine a *charged sphere* by the second method, the similarly charged pith-ball will float around it at equal distances in every part, thus proving that the sphere is surrounded by a layer or film of electricity, which has the same density or depth throughout (fig. 73).

FIG. 73.



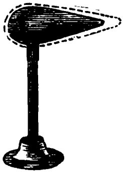
Charged Sphere.

FIG. 74.



Charged Cylinder.

FIG. 75.



Charged Ellipsoid.

This might also be shown by means of the proof plane touching different parts of the sphere; for the amount of charge, as shown by its effect upon the electroscope, would be found to be uniform in every part.

A cylinder with rounded ends, charged and similarly tested, would show greater depth at the ends, and lesser about the sides of it (fig. 74).

The charged ellipsoid shows greatest depth at the pointed end, less at the broad end, but least across the shorter diameter (fig. 75).

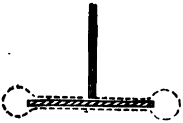
When *a disc* receives a charge it is accumulated with great density all around the edge of the disc, but in a very thin layer on either side of it. Such is the distribution on the disc of the electrophorus (fig. 76).

A charged cube has greatest density at the corners or points of the cube, less on the edges, but least on the faces of it.

From the examination of such bodies as those described, and others, it has been established that the *density* of the electricity of a charged body is *greatest at points and sharp edges*, *less on the sides*, and *least in hollows or depressions.* In all cases the conductor must be away from the influence of other conductors, or some disturbance of the regular arrangement may take place.

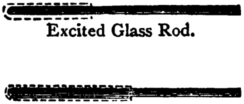
An excited rod has electricity developed uniformly on the portion rubbed, and it accumulates there with increasing density if the rubbed body be an insulator, as sealing-wax, ebonite, or glass (fig. 77). Should it be a conductor, as a brass rod held by some insulator, it spreads over the whole surface of the conductor (fig. 77); and is, consequently, of less density, and lower tension.

FIG. 76.



Charged Disc.

FIG. 77.



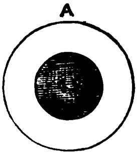
Excited Glass Rod.

Excited Metal Rod in Insulating handle.

Quantity, Area, Density, Tension.

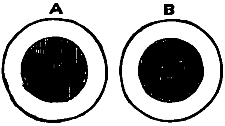
A charged sphere divides its charge equally with another insulated, neutral sphere of equal size, and the half charge from either of these will again subdivide equally with another similar sphere. This will illustrate the relation between area and amount of charge. If the area be doubled, the quantity remaining the same, the density or depth of the electricity is diminished by one-half. In diagrams (figs. 78, 79, 80), it will be perceived that, when one unit of charge is spread over two equal areas, the density in each becomes one-half of what it was in the former case. The half charge spread over two equal areas has its density reduced to one-fourth of the density of the original charge, *e.g.* Suppose a sphere A. (fig. 78) has a charge of electricity, represented by 48 units, and another equal but neutral sphere, B (fig. 79), be brought in contact with it and removed. The second sphere would share the charge equally with the first, and the quantity of electricity in each would then be represented by 24 units. If again either of these be brought into contact with another equal but neutral sphere as C (fig. 80) the charge is again equally shared, and each sphere then contains 12 units. Should this experiment be continued further, similar results will be apparent, and the equal subdivision of the charge maintained.

FIG. 78.



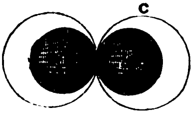
Charged Sphere.

FIG. 79.



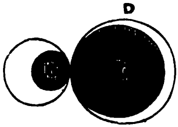
Subdivided Charge.

FIG. 80.



Further Subdivision of Charge.

FIG. 81.



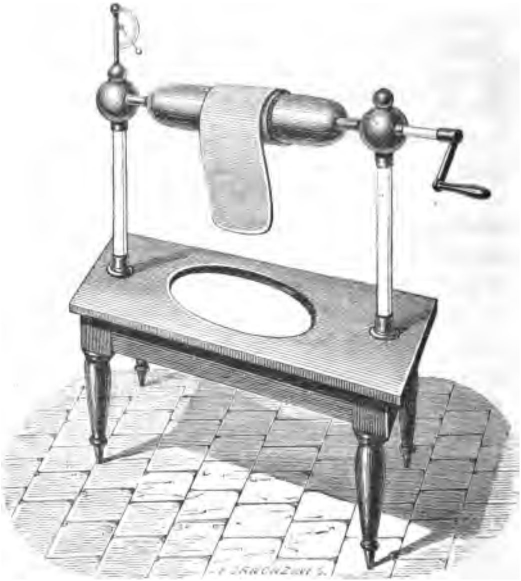
Subdivision of Charge.

If on the other hand the spheres be unequal, the distribution will be in proportion to the area of the surface to be covered. For example, suppose a sphere, having a certain area be charged with electricity, which we will represent by 50 units, and that another sphere, having $\frac{1}{4}$ the area be brought into contact with it. The charge will then be distributed over the increased surfaces in proportion to their areas. Now as one sphere is $\frac{1}{5}$ of the area of the whole increased surface, and the other $\frac{4}{5}$, the smaller sphere will take $\frac{1}{5}$ of the original charge, and the larger $\frac{4}{5}$ of it, or the quantity of electricity on each will be represented by 10 and 40 units respectively (fig. 81).

In considering and comparing spheres it should be borne in mind 'that *the area of spheres varies as their radii.*'

Another method of illustrating this principle, that alteration of area varies proportionately the density, is afforded by the apparatus represented in diagram (fig. 82).

FIG. 82.



Experiment showing relation between Area and Density of Charge.

A metallic cylinder is insulated at one end, to which the handle is attached, but is in metallic connection with a quadrant electrometer, fixed on a brass knob, at the other. The whole is supported on glass legs, and is usually fixed on a table, having an elliptical hole of sufficient size made in it.

To the metallic cylinder is attached a sheet of tin-foil, which can be wound up and unwound by turning the handle. Sometimes a silk thread is attached to the foil to assist the unwinding. If the tin-foil, when it is unwound, receive a charge of electricity, the quadrant electrometer rises to a certain height, which indicates the density or strength of the charge. Now, if the surface of the foil be reduced one-half by winding it around the metallic cylinder, the repulsion of the pith ball is doubled; if it be reduced to one-fourth, it is quadrupled; in each case the same quantity of electricity is present, but the surface over which it is spread has been diminished. The decrease of area has produced an increase of density. If the area be again increased by unwinding the foil the pith-ball gradually falls, but rises as gradually if the area be again decreased by rewinding.

From such experiments as these it has been proved '*that, quantity remaining the same, the density of the electricity varies inversely as the surface of the conductor.*'

Tension is the force with which the electricity of a charged body tends to pierce the air which surrounds it, and spark or discharge itself towards a neutral or another charged body. The tension always increases with the density, but not equally so; for example, twice the density does not imply twice the tension. The law relating to tension is this:—'*The tension is proportional to the square of the electric density.*'

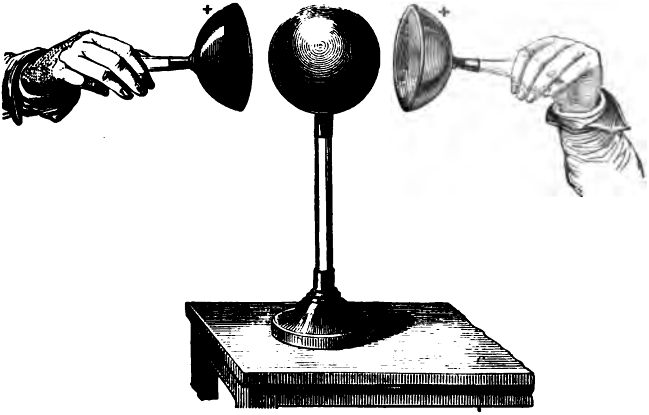
12. Distribution on Hollow Conductors.

Two metallic spheres, one solid and the other hollow, of equal diameter, fixed on insulating supports, will take from the same machine an equal amount of charge, for the electricity always accumulates on the surface; and its quantity depends upon the area of the external surface, and not upon the volume or mass of the body. Or if the solid ball be first charged, and the neutral hollow one be brought into contact with it, it will be found that the two balls will then equally share the charge. Also if the hollow ball be first charged, and the solid one be brought into contact with it, exactly similar results are produced. Tyndall states that 'Le Roi and D'Arcy showed that a hollow sphere accepted the same charge when empty as when filled with mercury which augmented its weight sixty-fold.'

A very striking and conclusive, but somewhat delicate, experiment on this phase of the subject is exhibited by what is known as Biot's experiment.

This experiment consists of covering an insulated charged brass or copper ball with two closely fitting hemispherical metal cups, which are insulated by being fixed to glass handles. On separating the cups with very great care the electricity will then be found on the outer surfaces of the cups, while the ball will show no trace of its previous electrical charge (fig. 83).

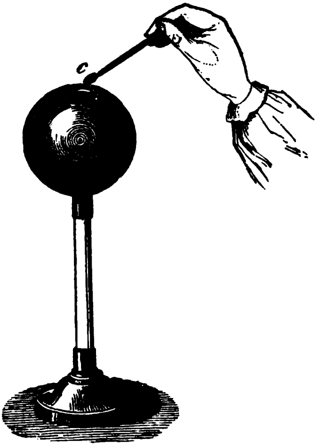
FIG. 83.



Biot's Experiment.

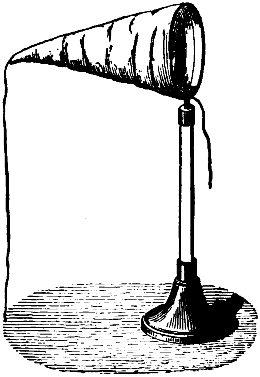
Another experiment, which proves that the charge of a hollow conductor is found on the outside of it, is to insulate a hollow sphere, which has a circular hole about an inch in diameter, for the insertion of a small proof plane. On charging the sphere, no electricity can be removed by the proof plane, if it be brought into contact with the interior by inserting it through the hole, which may be perceived by bringing the disc into contact with the gold-leaf electroscope; while if the proof plane be made to touch the outside the divergence of the leaves of the electroscope, as the disc is brought near it, is very apparent. Similar effects will be observed if a cylinder of wire gauze, a saucepan, a tin or pewter pot, or even a man's hat be insulated and used.

FIG. 84.



Hollow Brass Ball charged.

FIG. 85.



Faraday's Butterfly Net.

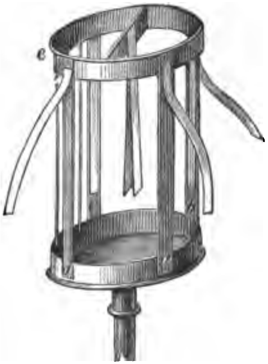
Faraday's Butterfly Net (fig. 85) is another experiment which conclusively illustrates the same principle. It consists of a conical gauze bag about 9 in. long, and 4 in. in diameter at the base of the cone. To the apex of the cone two silk strings are fastened, one to the inside, and the other to the outside. The bag is secured to a wire or narrow metallic strip, and supported on a glass rod coated with shellac varnish. The net, thus arranged, is capable of receiving an electrical charge from any electrified body. When it is charged, if it be tested with the proof plane and electroscope, the charge will be found to be on the outside of the net. The conical bag is now turned inside out by means of the silk string, attached to the interior of the bag; the electricity however, does not pass to the inside, but, when again tested, is still found on the outside, as at first. And, if the bag be reversed several times by means of the silk strings, the electricity always remains on the outside.

In order to still further test the application of this principle, Faraday constructed a cubical room, having a 12 ft. side, which was built with laths spread over with paper and wire gauze. This he insulated from the earth by ropes of silk. In this chamber he performed the most delicate experiments with electroscopes and electrometers, though the exterior of the room was so highly charged with electricity, that brilliant sparks were continuously drawn from it.

Delicate electroscopes and electrometers may be protected from the influence of highly charged bodies near them by being surrounded by a loosely fitting covering of gauze, muslin, or tin-foil. An electroscope, placed in an insulated bird-cage, or underneath an insulated gauze meat-cover, is unaffected when a charged body is brought near to it. It is also not disturbed if the cage or meat-cover receives a high charge from an excited body, for then the charge accumulates on the outside of the hollow conductor, and does not affect the electroscope within.

Another experiment in which this may be plainly exhibited is described in Ganot's 'Natural Philosophy' in the following way:—'Two tin-plate rings, about 8 to 10 inches in diameter, are connected by four thin vertical tin-plate strips, *a*, *b*, *c*, *d*, and by twenty-four vertical wires, with each other; with the exception of two, the latter are not shown so that the interior of the apparatus may be seen. To each of the vertical strips a paper band is fastened both inside and out, and a similar pair of strips is suspended to a cross bar. If this apparatus is insulated, and connected with an electrical machine at work, the outer paper strips are repelled, while those in the interior show no signs of electrical repulsion.'

FIG. 86.



Apparatus to illustrate Distribution of Electricity

There are *two cases in which the law respecting distribution on the outside of a conductor does not hold good.* One is, *when electricity passes* in a current *through a wire*; then the greater the section of the wire the more easily the electricity passes through it, and if two wires of the same diameter be used, one of which is solid and the other hollow, the solid wire conveys the electricity the better of the two. Th other is, *when an insulated charged body is brought into an insulated hollow conductor.* By the inductive action of the charged body the two electricities of the hollow conductor are decomposed, the opposite electricity is attracted to the inside of the conductor, and the similar kind repelled to the outside. On withdrawing the charged body the two electricities recombine, and the conductor returns to its neutral condition. This may be shown by bringing an insulated charged ball, or an excited ebonite rod into a tin cup, having a wire from its outside connected with an electroscope. On placing it within the cup the leaves of the electroscope diverge, but collapse if it be withdrawn. If, while the leaves are repelled with similar electricity, they be tested, the charge will be found to be of the same kind as that of the charged body within the hollow conductor. By touching the outside of the cup, the free electricity, which charges the electroscope, passes to the earth, and the leaves collapse. On removing the hand, and then the charged body from the inside of the conductor, the leaves again diverge with the electricity, which was previously held bound on the inside of the hollow conductor by the presence and influence of the charged body. If this be tested, it will be seen to be of the opposite character to that which was placed within the conductor, and no electricity will be found within the cup.

Experiments.—Charge insulated sphere, cylinder, ellipsoid, disc, and cube from excited rod, or, better, from an electrical machine. Test density with proof plane and electroscope: notice different divergence of leaves as different parts are tested; also test each by similarly charged pith-ball of electric pendulum, and note distance of pith-ball from conductor in each case.

Insulate a sphere, either by hanging it from a silk string, or supporting it on a glass rod. Charge it with electricity. Bring another insulated and equal sphere into contact with it. Test the charges of the two spheres in both ways. Bring a third equal and insulated sphere into contact with either, and test charge of each after contact—they will subdivide again equally. Show by means of apparatus (fig. 82), or by tin-foil fixed to a glass rod, that when the area is reduced by one-half the density of the electricity is twice as great. Show also, generally, that when area is diminished density increases, but when area is increased density is diminished. To exhibit this attach wire from tin-foil to electroscope, roll tin-foil on and unroll it from glass rod, mark increase and decrease of the divergence of the leaves as this is done. Obtain two equal metallic spheres, one solid and the other hollow; insulate them; charge the solid one, and bring the hollow one into contact with it; compare the charges—equal. Discharge each. Next charge the hollow one, and bring the solid one into contact with it; compare charges again—equal. Same result apparent in both cases. Show Biot's experiment, if possible; prove electricity passes to the outside by removing it on the cups. Charge hollow sphere, having a circular hole in the top; pass proof plane through hole to inside of sphere, touch electroscope: no effect on leaves. Bring proof plane to the outside, then remove to electroscope: leaves diverge.

Charge and test similarly cylinder of wire gauze, saucepan, tin, or pewter pot, or man's hat. No charge will be found inside any of these hollow conductors.

Exhibit, describe, and test Faraday's butterfly net. This experiment requires care.

Cover electroscope loosely with muslin or gauze bag; bring a

Google

charged body near: the leaves are not disturbed. Place electroscope in bird-cage or under meat-cover insulated, and bring an excited body near: no effect on leaves—electricity on the outside. Prove this also by apparatus similar to that represented in diagram (fig. 86).

Rest tin cup or other hollow conductor on insulating stool or stand, and insulated charged body within it. Connect outside with electroscope by wire: leaves diverge. Test kind of electricity in leaves—same as charged body within conductor; touch outside of cup, leaves collapse; remove hand, then charged body from inside conductor—leaves of electroscope again diverge. Test kind of electricity—opposite kind to that of body placed within, and the electricity which was on the outside. This is the electricity which was bound on the inside of the hollow conductor.

13. Action of Points.

Points and sharp edges, when they form part of a charged conductor, permit a very rapid interchange of the electricity with the surrounding atmosphere, and thus quickly restore the body to its neutral condition.

Again, a point, which is in conducting connection with the earth, brought near to, and presented towards a charged body, is acted upon inductively by that body; the opposite electricity is attracted from the earth through the point, and discharged on the body; while electricity from the body is discharged in equal quantity to the earth. The sharper the point, the more perfect is this discharge. The effect of the action of a point may be exhibited by fixing a quadrant electrometer on the prime conductor of an electrical machine, and letting the point of a needle project from the conductor. On turning the machine the electrometer ceases to rise, for the conductor is almost neutralised by the action of the point. If the point be removed, the electrometer rises to its usual position.

Next, if the point be held in the hand, and presented to the prime conductor, similar results follow, as in the previous case. On covering the point with the finger the electrometer again rises, but falls as soon as it is uncovered. Another good means of illustrating this is by attaching a tassel of tissue paper by means of a deal rod to the prime conductor. As the prime conductor becomes charged, the tissue tassel is also charged with the same kind of electricity, and the separate strips repel one another. On presenting a point, those strips which are near it immediately collapse, but diverge again, if the point be covered. The tension of the electricity of the prime conductor is considerably reduced by a point projecting from it, or one in earth-connection directed towards it. Only a very feeble spark can be obtained in either case. The latter arrangement resembles the principle and action of the lightning-conductor, that destroys the tension of the cloud hovering above the building which the pointed conductor is intended to protect.

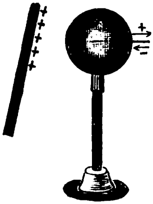
If the hand be held near the point when the prime conductor is charged, the electric wind, or rush of repelled air particles, is felt. This is known as the *electrical aura.* It will act like a fine stream of wind on a candle flame brought near it, and will drive away a strip of tissue paper held towards it.

In the prime conductors of electrical machines points are used to permit of the more rapid charging of the conductor by the interchange of electricity from the excited glass to the conductor, and from the conductor to the glass. A point, or a series of points, projecting from the rubber of an electrical machine into the air, would enable the prime conductor to become charged, even when the machine was perfectly insulated from the earth. The points secure the same necessary interchange with the atmosphere that a wire or chain connection does with the earth.

An ordinary sewing needle, held in the hand, and the point of it passed up and down over the different parts of a highly excited glass or ebonite rod, is one of the best ways of thoroughly discharging it.

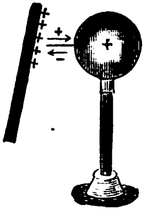
The influence of a point, when it is attached to a conductor, may be illustrated by experiments similar to those represented in the diagrams (figs. 87, 88). In the first case *the point is on the portion of the conductor away from the excited rod.* Here the presence of the positively charged rod decomposes the two electricities of the conductor, attracting the negative, but repelling the positive. The negative is held bound by the presence of the inducing rod, but the free positive interchanges with the negative of the air through the point. Should the rod be withdrawn without removing the point, the conductor will become quickly neutralised ; but if the point be removed by means of some insulator before the rod is withdrawn, on the removal of the rod the conductor will be found to be negatively charged.

FIG. 87.



Point in Conductor away from Excited Body.

FIG. 88.



Point in Conductor towards Excited Body.

This method of charging (fig. 87) is similar to charging by induction (see p. 41), when the charged body has the opposite electricity produced in it to that of the exciting body. The point here also serves the same purpose for discharge into the atmosphere as the earth connection does with the earth. In the second case *the point is towards the charged body*, and now its use resembles the points of the prime conductor of the electrical machine. The excited rod acts inductively on the ball, decomposing the electricity. Negative is drawn towards the rod, and positive is repelled from it. The presence of the point allows a free interchange of electricity between the rod and the conductor, under the influence of which the conductor becomes positively charged. If the rod be withdrawn and the point quickly removed by means of some insulating substance, the ball remains charged positively, whereas, if the point remain attached to the conductor, the ball will be neutralised from the interchange of electricity with the surrounding atmosphere. This method of charging a conductor is the same in effect as charging by contact, for the conductor in this way is charged with the same kind of electricity as that of the electrified body.

A pith-ball suspended by a fibre of silk, and having a sharp point projecting from it towards a charged body, is repelled when brought near it, from the interchange of electricities from the charged body to the point, and from the point to the charged body.

The movements of the wire frame in the electrical whirl, and the electrical inclined plane described p. 56, are illustrations of the discharge of electricity through points.

Experiments.—Let a point project from a conductor away from electrified body; try to charge it while the point remains. Present a point to conductor while it is under induction; remove rod first, then remove the point. Repeat the experiment; remove point first, and then remove rod or excited body. Contrast effects in each case.

Attach point, as pointed brass rod, or needle, to prime conductor of machine, and fix a quadrant electrometer also to it. Turn machine, the presence of the point prevents the rise of the pith-ball. Remove the point, the pith-ball rises as usual. Present a point, held in the hand, to the charge prime conductor—the pith-ball immediately falls, and will not rise again until the point be withdrawn altogether. Notice effect of covering point with finger, and again uncovering it on the rise and fall of the electrometer.

Attach tassel of tissue-paper to prime conductor, and test in similar manner.

Show decrease of tension of spark, if point be allowed to project from, or be presented towards, the prime conductor.

Exhibit electrical wind by its action on candle-flame, and on strip of tissue-paper, held near the point.

Insulate an electrical machine by placing it on a large warm sheet of plate-glass; attach a row of points to the rubber away from the machine. Charge machine without earth contact.

Excite glass rod; show difficulty of discharging it. Take sewing needle, move point up and down the rod, and turn rod as this is done: perfect discharge. Test with electroscope. Fix point in insulated conductor; bring excited body to opposite part of conductor; while under induction remove point with insulator, conductor charged with opposite electricity. Restore point, bring excited body towards point; remove again with insulator, conductor charged with similar electricity.

Suspend pith-ball from fibre of raw silk; attach a fine point to it. Show repulsion of pith-ball as excited body is brought towards the point.

Show movements of electrical whirl and electrical inclined plane as illustrating strikingly the effect of the discharge of electricity through points.

14. Electrical Discharges.

Whenever there is an interchange of electricity of sufficient tension from a charged conductor with the induced opposite electricity of an otherwise neutral body, or when two oppositely charged conductors interchange with one another, two effects are always apparent, which announce the discharge, viz. the spark and the report. The spark is of exceedingly short duration, lasting only about $\frac{1}{24000}$ part of a second, but it is of great brilliancy. It takes one of three forms—straight, sinuous, or zigzag, depending upon its length. The two latter are generally obtained from the prime conductor of an electrical machine under the most favourable circumstances, and these also are dependent to some extent on the kind of machine, and the state of the atmosphere. Dry frosty weather is the best for electrical experiments.

This interchange of electricity, which is known as the Electrical Discharge, is capable of producing a variety of effects, such as luminous, chemical, heating, mechanical, magnetic, and physiological.

Luminous Effects.

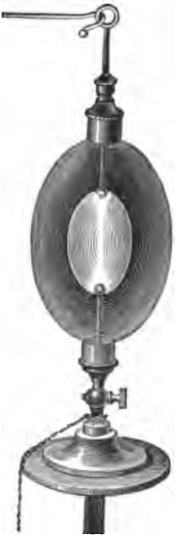
Besides the spark discharge there are others which are known as the brush and glow discharges. The former may be illustrated by placing a small knob on the prime conductor of an electrical machine, or by sticking a pin into it, and allowing the discharge to take place in the dark from the head. The discharge from the pin's head forms a divergent cone of light. The brush discharge is sometimes visible from the masts of ships, from the bayonets of soldiers, or, under very high electrical induction, even from the fingers of the uplifted hand. Under such conditions the discharge is known as '*St. Elmo's fire.*' If a very sharp point, like that of a needle, be used, and allowed to project from the prime conductor, the discharge takes the form of a brilliant point of light, which is plainly noticeable in a dark room, and is known as the electric glow. The spark discharge is practically instantaneous; but the brush and glow discharges are continuous. By suitable arrangements this apparently instantaneous spark may be made to exhibit brilliantly illuminated designs. To produce these, the design, word, or motto, must be arranged on a sheet of glass by means of small pieces of tin-foil, pasted or gummed so near each other as to be within easy sparking distance. The plate of glass is enclosed in a wooden frame. To the frame, and in metallic connection with the foil, a knob is fixed at the beginning of the design, and a ring is similarly connected with the end of it. To this ring a chain is attached, for the purpose of securing good earth connection. The most common illustrations of this are seen in the words 'Fire' and 'Light,' and what are known as the 'luminous spiral' and the 'luminous star'; but sometimes elaborate floral designs and longer words are prepared for exhibiting this effect.

The brilliancy of the spark is considerably increased by the discharge from a highly charged Leyden jar, or better still from a Leyden battery. The battery discharge may by means of the Universal Discharger be sent through various substances, as egg, series of eggs, lemon, ivory ball, lump of sugar, with varied illuminating effects. A Leyden jar, having its inside and outside coatings lined with lozenge-shaped strips of tin-foil, or dotted over with tin-foil spangles, shows brilliant effects as it is charged, but much more as it is discharged. This is the luminous jar.

The colour of the discharge is affected by the character of the air through which the electricity passes. Under ordinary circumstances it is white, but in rarefied air it assumes a reddish or violet tinge.

To exhibit this effect apparatus must be employed as shown in fig. 89. It consists of an oval closed glass vessel, into which passes, from top and bottom, air-tight, a rod terminating in a ball. The lower rod is fixed, but the upper one moves up and down through the brass cap, the leather padding of which renders it air-tight. The brass cap at the bottom is furnished with a stop-cock, so arranged that it may be screwed into an air-pump. After the air within the vessel has been exhausted, the vessel is again securely screwed into the heavy foot to which it is usually fixed. On adjusting the knobs to meet the condition of the machine, and completing the earth connection, the machine is turned. A violet light is then seen extending from knob to knob. On gradually admitting the air the light assumes its usual white character; and instead of being continuous, is only seen as an ordinary intermittent spark. This is known as the *electric egg discharge*. Some electrical machines enable the discharge to pass through highly exhausted tubes with the most beautiful effects. These tubes are named Geissler's tubes, or vacuum tubes. The colour of the spark depends upon the substance from which it is taken: from gold it is green; from silver, red; tin and zinc, white; and from water, orange or yellow.

FIG. 89.



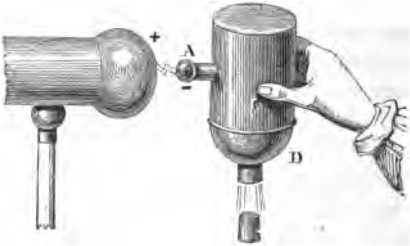
Electric Egg.

Chemical Effects.

The chemical effects of the electrical discharge are not so strikingly exhibited, as they are by the passage of the Voltaic current. High tension discharge sometimes decomposes, and at other times recombines compound bodies. The former is seen when a wire from the prime conductor is brought into contact with a piece of blotting-paper, soaked in iodide of potassium and starch water, which has a wire from the opposite end of it connected with the earth. On the paper nearest the prime conductor brown spots will be noticeable ; if blue litmus paper be used, the spots will be red. With regard to recombination, if oxygen and hydrogen be collected in their combining proportions—one of the former to two of the latter—in a eudiometer, that is, a tube into which two platinum wires are fused, and a high tension spark be passed through the mixture an explosion announces the chemical combination of the two gases, and a deposit of vapour is the water thus produced.

Volta's Pistol is constructed on this principle. Two volumes of hydrogen and one of oxygen are placed in a brass vessel, and the opening is closed with a cork. A short rod, terminated at each end in a knob, passes into the vessel. On a spark passing from an electric machine to the

FIG. 90.



Volta's Pistol.

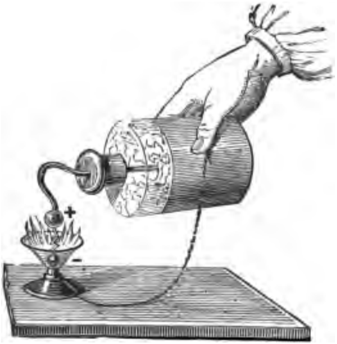
outer knob, another discharge takes place within the vessel; the gases instantly combine with a loud report, and the heat generated causes such an expansion of the vapour of water that the cork is driven from the vessel with some amount of force.

The formation of ozone is another chemical effect of the electrical discharge. It is produced when electricity of high tension escapes through a series of points into the air, and may be easily recognised by its peculiar odour. If a piece of blotting paper, which has been soaked in a solution of starch water in which a crystal of iodide of potassium has been dissolved, be held towards the head of a pin, projecting from the prime conductor of an electrical machine, a brown colour is produced on the damp paper, as the machine is turned. This colour is due to the action of ozone.

Heating Effects.

By means of the electrical discharge from the prime conductor of a good machine, or of a highly charged Leyden jar, ether, bisulphide of carbon, and alcohol may be ignited; and with a suitable arrangement the gas may be lit. A vessel similar to that shown in fig. 91 is generally used for experiments with liquids. They may, however, be ignited in a small spoon if it be heated slightly before the experiment is tried.

FIG. 91.



Igniting Ether by spark from Leyden Jar.

To light the gas from the machine a person should stand on an insulating stool, and place the hand upon, or be otherwise in metallic connection with the prime conductor. This may be done by fastening a chain to the prime conductor, and holding the end of it in the hand. On presenting a brass conductor held in the other hand to a gas jet, through which the gas is escaping, the discharge immediately lights the gas. A piece of ice, held in the hand, may also be used, and so may the unprotected finger, but a little care will be necessary in performing this last experiment.

If the Leyden jar be used for the experiment, it should first be charged highly from the electrical machine; the gas should then be turned on, and the knob of the jar be brought some little distance above the jet. The ordinary discharge of the jar will now ignite the gas.

From the discharge of a Leyden battery a platinum wire may be heated to a red heat, a white heat, and sometimes volatilised. Gunpowder and gun-cotton may be exploded by introducing a wet string, or a wet piece of glass tubing in the circuit, so as to delay the discharge slightly.

Mechanical Effects.

By the ordinary discharge of a Leyden jar a card may be punctured, and the hole will show a fraying on both sides of the card, as if the discharge had passed both ways from the middle of the card.

The discharge from a Leyden battery will puncture a sheet of glass of different thickness, according to the strength of the battery, and a strong battery will split a piece of wood half an inch thick, if the discharge strike it in the direction of the fibre.

When a Leyden jar is very highly charged, and its glass is not uniform throughout, or when a jar has been highly charged and allowed to stand for a time, the two electricities in their endeavour to reach one another sometimes pierce the glass, and produce what is known as the *disruptive discharge*, thereby spoiling the jar.

Magnetic Effects.

If needles or thin strips of steel be so arranged that a series of sparks from an electrical machine, or a discharge from a highly charged Leyden jar, or Leyden battery, be sent across them at right angles, the needles or strips will be magnetised. A thin rod of steel, round which a spiral of insulated wire is wound, becomes magnetic under similar influences. The needle of a delicate Astatic galvanometer (see Part III.) will be deflected by the electrical discharge from the high tension electricity of a powerful machine, if a wire from the prime conductor be fastened to one binding screw of the galvanometer, and a wire from the other binding screw be placed in earth connection, or attached to the rubber.

Physiological Effects.

When the discharge is taken from the prime conductor of an electrical machine by the knuckle of the finger, a slight pricking sensation is experienced, which becomes more severe as the tension of the electricity is increased. The discharge of an ordinary charged Leyden jar is felt in the arms; of a highly charged jar, across the chest; and of large jars, highly charged, in the stomach. The shock obtained from large Leyden jars, or from Leyden batteries, are sometimes dangerous. Rats and cats have been killed by such discharges. Not only may a shock be felt by *one* person who discharges a Leyden jar, but if several persons join hands, and grasp one another firmly, the person at one end holding the outer coating, while the one at the other end of the party touches the knob, the shock is felt by each individual in the circuit at the same time. The violence of the shock depends upon the size of the jar, and the intensity of the charge. Those persons at the end of the chain feel the shock with greater intensity than those in the middle of it.

Professor Tyndall states that 'the Abbe Nollet formed a line of one hundred and eighty guardsmen, and sent the discharge through them all.' The discharge on two occasions struck Franklin senseless; and from accidentally receiving the discharge of fifteen large Leyden jars, Tyndall experienced peculiar optical disturbance or derangement. Describing this accident he remarks, 'For a sensible interval of time life was absolutely blotted out, but there was no trace of pain.' He regarded this as an experimental proof that people killed by lightning suffer no pain.

Lichtenberg's Figures.

These peculiar coloured figures are produced on an insulating substance—a cake of resin or ebonite is the best—by drawing patterns on the surface of the insulator, with the knob of a Leyden jar charged positively, or the knobs of two Leyden jars—one charged positively, and the other negatively. If only one jar be used, the surface of the insulator should first be excited, and then the lines traced on it with the opposite electricity of the knob; but if two oppositely charged jars are used, the excitement of the surface is unnecessary. After the tracings have been made, finely powdered red lead and flowers of sulphur, mixed together and placed in a fine muslin bag, should be sprinkled over the surface of the insulator. By friction with one another and the surface of the muslin, the red lead becomes positively electrified, and the flowers of sulphur negatively; and accordingly the red lead arranges itself along the negative tracings, and the flowers of sulphur over the positive. In this way very pretty designs may be produced. Should the whole surface be excited negatively, and lines be traced on it with the knob of a positively charged jar, the whole of the surface will be red, varied by the yellow tracings of the flowers of sulphur; but if both jars trace lines on an otherwise neutral surface, the tracings will consist of red and yellow patterns, varying somewhat in general characteristics.

Effect of Heat on Electrical Discharge.

An iron ball at a white heat cannot be charged with electricity if brought into contact with a charged body. In this it resembles the indifference to magnetism of a white-hot iron ball. As the ball cools, it first accepts a charge of negative electricity, when it reaches a bright red heat; and it is some time—not until it becomes of a dull red—that it shows a disposition to accept a positive charge. Soon after this condition is reached it receives a charge of either kind equally well. These statements may be proved by placing a white-hot iron ball on a gold leaf electroscope. At that temperature the electroscope refuses to receive a charge. As the ball cools the electroscope may be charged negatively, but the cooling must be continued for some time before the electroscope will accept a positive charge.

A similar effect is apparent if an electroscope be discharged by the presence of a hot ball. If it be at a white heat and earth-connected, it discharges a positively or negatively charged electroscope equally well. As the temperature falls to a red heat a negatively charged electroscope would be discharged; but a positively charged one would require a still lower fall of temperature. This portion of the subject has been carefully investigated by Professor Guthrie.

Action of Flames.

Flames act like white-hot metallic bodies in the discharge of electricity, and the cause of their action is due to the motion of the air-particles arising from heat, and not, Guthrie remarks, 'that the particles of the vapour or gas act like a multitudinous collection of points affording egress to electricity of one kind, and ingress to that of the other.'

Effect of Evaporation on Discharge.

This may be shown by placing a small metallic vessel containing water on the disc of a gold leaf electroscope. If the electroscope be negatively charged, it is discharged almost instantly; while, if positively charged, it is scarcely altered in any way. This, again, is similar to the action of heat and flame on charged bodies.

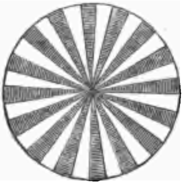
Induced Currents by Discharge.

Induced currents arising from a discharge of frictional electricity are best illustrated by means of flat spirals of insulated copper wire. These should be brought close together, and be parallel with one another. The one which is to receive the spark from the electrical machine or Leyden jar, and is to convey what is termed the primary current, must have a knob at one end of the spiral, and the other end must be in good earth connection. The second spiral should terminate in two knobs, which lie near each other. When a spark passes to the first spiral, a current proceeds through it to the earth. This induces a current in the second spiral, which passes through it in an opposite direction to that passing through the first, and is named the secondary current. It is instantaneous in its action, and is shown by a spark passing between the two knobs at the ends of the second spiral. By suitable arrangement a current may be made to pass through a third spiral, which is induced by, and is in the opposite direction to, the secondary current. This is known as the tertiary current. Each current is momentary in its action, and is proved to exist by the sparks which pass between the knobs that are near one another and attached to the terminals of the spirals.

Duration of Spark.

Electric sparks appear to last for a much longer time than they do in reality. This is due to the fact that the impression made on the retina of the eye continues some time after the light which produced the impression has ceased. Its exceedingly short duration may be experimentally shown by rapidly rotating a disc, divided into an equal number of black and white sectors, as in the diagram, fig. 92, in a darkened room, and illuminating it with the spark from a highly charged Leyden jar.

FIG. 92.



Discs with equal Sectors.

As the discharge takes place the disc appears to be quite still, and several of the black and white sectors are distinctly visible with intermediate grey ones. In order that each separate sector may be distinctly visible the spark must be instantaneous.

From a calculation based on an experiment of this kind the duration of the spark is considered to last $\frac{1}{24000}$ of a second.

Velocity of Electricity.

From the investigations of Wheatstone with a revolving mirror, and the discharge of a Leyden jar through half a mile of wire, it has been considered that electricity has a velocity of 288,000 miles in a second; and it has also been ascertained, that what appears a single discharge between two bodies is in reality two discharges in opposite directions between them. Kirchhoff calculated the velocity to be 192,924 miles in a second, which is about the same as the velocity of light. Walker gives it as 18,400 miles per second, according to others it is 62,100 miles in iron, and 111,780 in copper wire. The nature of the conductor diminishes the velocity, so does the resistance of the wire. Insulated submarine wires, like ocean cables, reduce the velocity considerably.

A means of illustrating the great velocity of electricity is furnished in the luminous spiral, the luminous pane, and experiments of a similar character. The numerous breaks between the various small pieces of tin-foil produce really a succession of discharges, as the discharge from the prime conductor passes across them ; yet they take place so rapidly after one another that the eye fails to distinguish any difference as to the time of each ; consequently, the whole succession of sparks seems to appear together, and the design to be continuously illuminated.

Experiments.—Show spark discharge—straight and zigzag.

Stick large pin into the prime conductor of electrical machine, notice discharge as the machine is turned—brush discharge. Fix needle into prime conductor so that point may project, notice brilliant speck of light at point—glow discharge.

Pass discharge through words 'Fire' or 'Light,' through device, and luminous spiral.

Charge Leyden jar highly and discharge it—brilliant white spark. Charge luminous Leyden jar, notice sparks as charging proceeds, and brilliant effect as jar is discharged. Discharge highly charged Leyden jar, or Leyden battery through egg, series of eggs in glass tube, lemon, ivory ball, and lump of sugar—observe luminous effects.

Exhaust electric egg, and pass series of discharges rom prime conductor of a good electrical machine through it, the violet glow will be continuous. Admit air, notice change to white intermittent spark.

Place piece of gold, as sovereign or half-sovereign, on prime conductor, take spark from it ; do the same with shilling or sixpence, copper, zinc, or tin ; the sparks will be of various colours.

Soak blotting paper in a solution of iodide of potassium and starch, while damp bring it to prime conductor, having head of pin projecting from it ; the formation of ozone colours the damp paper.

Ignite ether and alcohol in a small spoon by discharge from machine, and again from highly charged Leyden jar. For the igniting of ether the spoon should be slightly warm, but for alcohol made hotter. A better means of performing the experiment is provided by the apparatus shown in p. 103.

Light gas with brass rod, piece of ice, or finger, by standing on an insulating stool, and resting one hand on the prime conductor, or holding a chain attached to it. Do it also by discharging a Leyden jar just above a jet, through which the gas is escaping.

Explode gunpowder and gun-cotton on table of universal discharger. Each should be placed between the knobs, and a piece of wet string inserted in the circuit to secure the success of the experiment.

Rest a card, held in the hand by a corner, on the knob of a Leyden jar, discharge the jar by bringing the lower knob to outer coating, and the upper knob above the card—small hole pierced in card ; examine its character, frayed both ways.

Discharge Leyden battery through sheet of glass, and piece of wood in direction of fibre.

Lay a strip of tin-foil on a sheet of varnished glass. Place a steel needle or piece of steel wire beneath the foil, and another piece above it. Each should be at right angles to the foil. Send several sparks from a highly charged Leyden jar or battery along the tin-foil. Exhibit magnetisation and compare polarities.

Connect a wire from prime conductor with one binding screw of Astatic galvanometer, and take a wire from the other binding screw to the earth, notice deflection of the needle as the machine is turned.

Charge Leyden jar and discharge it through class, joining hands—physiological effect.

Excite cake of resin or ebonite, trace figures with knob of positively charged Leyden jar. Sprinkle powdered lead and flowers of sulphur from fine gauze bag over cake, the red lead adheres to the negative part of the cake, and the flowers of sulphur follow the tracings.

Take a neutral insulating cake, and trace figures with two Leyden jars, one charged positively and the other negatively. Shake powders over the cake ; red lead follows the tracings of the negative jar, and flowers of sulphur the positive. Contrast different results in each case.

Heat an iron ball to a white heat, insulate it, bring it near the prime conductor of an electrical machine, attempt to charge it, test it with gold leaf electroscope ; no effect. Test it, when at a bright red heat, receives negative charge ; try positive, no effect. At lower temperature, dull red, test positive again, now held. At lower temperature still, try both—each equally well retained.

Bring white hot, earth-connected ball near electroscope charged positively, and another similar ball near another charged negatively, both will be discharged equally well. As the temperature of the ball falls, negative is first discharged, and, afterwards, positive.

Light lucifer match and hold it over the disc of an electroscope, the electroscope will be discharged if charged with either positive or negative.

Soak some cotton wool in alcohol, wrap wire around it, light the wool and hold the flame over the disc of an electroscope, the flame will discharge the electroscope.

Place water in a small metallic dish on the disc of an electroscope; compare difference of effect when the electroscope is positively or negatively charged.

Show induced currents with flat spirals. Rotate disc divided into numerous equal black and white sectors, notice uniformly grey appearance. Darken room and discharge highly charged Leyden jar; notice some black and white sectors are distinctly seen, some are not so, due to spark not being absolutely instantaneous. Procure a Newton's disc, a circular card, consisting of the seven prismatic colours arranged in their due proportion, rotate it, and illuminate it with a brilliant spark, the various colours are seen almost distinctly.

15. Electrometers.

It is frequently necessary to know not only the character, but also the strength of the electricity of a charged body, and to ascertain the force or intensity of the action of one charged body upon another, or upon a neutral body at a distance from it. This is determined by the use of an electrometer.

The simplest forms of electrometers are, the electric pendulum, and the gold leaf electroscope. They, however, only roughly indicate the difference in intensity of charge. They are properly electroscopes, enabling us to see that electricity is present, rather than electrometers, which provide us with a means of determining accurately the relative strength or intensity of charge.

The chief electrometers in use at present are:—Henley's Quadrant Electrometer, Coulomb's Torsion Balance, the Peltier Electrometer, and Sir William Thompson's Quadrant Electrometer.

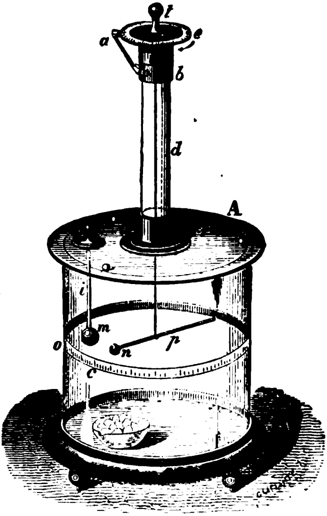
Henley's Quadrant Electrometer.

The description of this electrometer will be found on p. 51.

Coulomb's Torsion Balance.

This electrometer, which was constructed by Coulomb, was the first instrument of a delicate character, used to measure the intensity of the electrical charge. By a series of experiments with it, and others with the 'Magnetic Torsion Balance,' he proved that the same law, as regards influence at a distance, applied to electricity as to magnetism, viz., 'That the repulsion or attraction between two electrified bodies varies inversely as the square of the distance between them.' He also established another law, 'That distance remaining the same, the force of attraction or repulsion between two electrified bodies is directly as the product of the quantities of electricity with which they are charged.'

FIG. 93.



Coulomb's Torsion Balance

The apparatus he used is represented in fig. 93. It consists of a cylindrical glass vessel, covered with a glass top. Through the centre of this cover is a hole, and near the side another hole. A glass tube *d* is fixed, so that its centre may be over the centre of the glass plate, and at the top of the tube are two brass discs *t* and *e*. The upper one is divided into 360°, and to the lower one a pointer *a* is attached to mark the number of degrees the upper disc has turned. From the centre of the upper disc a very fine silver wire hangs. This passes through the middle of the glass tube, and as far as the middle of the cylinder. To the end of this wire a thin shellac rod is fastened at its centre *p*, and carries at one end of it a small disc of thin metal foil *n*. Through the hole near the side of the vessel, a conducting rod passes, having pith-balls, *r* and *m*, at each end of it, one outside, and the other inside the glass cylinder. The inner ball extends as far down into the vessel as the disc attached to the glass rod is situated, so that the two may be brought into contact with one another.

A graduated scale *o* passes around the cylinder at this height, so that the deflection of the disc from the pith-ball may be easily measured. Although the calculation of the electrical laws by the 'Torsion Balance' belongs to the advanced rather than to the elementary stage, yet an examination of one of them will be necessary to illustrate the action of the apparatus.

Coulomb's Experiment.—Coulomb experimented with this apparatus to prove the law applicable to the action of electricity at a distance.

In one experiment his charged body deflected the disc through an angle of 36°. He brought the disc back half the distance, or to 18°, by turning the upper disc 126° as marked by the index. Now in the first case the force tending to bring the disc back to its first position, when it was 36° away, was the torsion or twist of the wire, due to the 36° deflection of the disc. When, however, it was brought back against the same force of repulsion to 18° by turning the upper disc through 126°, the force then acting on the ball, and tending to bring it to the zero of the scale, would be 18° due to the torsion of the wire, and the force of 126° communicated by the turning of the upper disc. These may be compared, and numerically represented in the following way :—

1st force due to torsion of wire	36°
2nd force due to torsion of wire	18°
2nd „ turning upper disc	126°
Total force	144°

The intensities therefore are as

36 : 144 or as 1 : 4.

that is *at half the distance the intensity is four times as great.*

Note.—Before the Torsion Balance is used, the disc and ball must be in contact with each other at the zero of the graduated circle; and the pointer of the upper disc must be also at its zero.

The Peltier Electrometer.

The action of the Peltier electrometer is based on a comparison of the repulsion of a movable rod from the charge of electricity communicated to the apparatus of which it forms a part, and the position to which it is brought by the influence of the earth's magnetism upon the small magnet on which the rod lies.

Sir William Thompson's Quadrant Electrometer.

This is a more delicate instrument than either of those already described, and gives us an easy and accurate method of determining the character and intensity of the electrical charge; but as it belongs properly to the advanced portion of the subject, it will only be thus briefly referred to here.

Experiments.—Exhibit tension of electricity of prime conductor under different conditions by Henley's Quadrant Electrometer.

Test other electrometers if possible.

16. Atmospheric Electricity.

The electricity of the atmosphere is sometimes positive and sometimes negative. When the sky is clear, it is always positive; but during the formation of rain, hail, snow, mist and fog, it is sometimes negative with frequent changes to positive; and from positive again to negative, at times exceedingly rapid. It is thus possible for two masses of cloud near one another to be in opposite electrical states; and, when the tension becomes sufficiently high, they discharge towards one another by means of a *visible flash*, which we name *lightning*, and we hear a *report or peal* termed *thunder.* Again, the earth is the great reservoir of neutral electricity; but the surface of the earth beneath highly charged clouds has the opposite electricity to that of the clouds induced on it. If the electricity of the clouds be positive, that of the earth beneath them will be negative; but, if the clouds be negative, the earth's surface will be positive. Should these two electricities be kept from discharging gradually and silently towards one another by a layer or a series of layers of dry air, the tension of each increases according to the development of electricity in the clouds. If this be rapid, the attraction of the two electricities for one another soon becomes so strong that, like the two electricities on each side of the condenser, and Leyden jar, they *sometimes pierce the dielectric separating them*, and produce what is described (p. 61) as a *disruptive discharge.* This generally takes the form of a long zigzag spark, and is due to the interchange of electricity from the clouds to the earth, and from the earth to the clouds. We call this spark lightning, and it is the most dangerous form of electrical discharge.

In considering atmospheric electricity we cannot fail to notice the resemblance between the development of a thunderstorm, and the charging of a fulminating pane or Leyden jar. The clouds on which the electricity is produced resemble the action of the collecting plate, the surface of the earth the condensing plate, and the dry air between them the dielectric separating the metallic surfaces.

Lightning.

Electrical discharges produce lightning of three kinds :—

Sheet Lightning,
Forked Lightning,
Globular Lightning.

Sheet Lightning is considered to be either the result of a discharge of electricity, which illuminates the whole mass of the cloud where it takes place; or the reflection of a very distant discharge, which flashes at times across the horizon in summer nights, and is also known as heat lightning. Thunder is sometimes heard in the former case, but not in the latter, on account of the distance of the discharge from the observer.

Forked Lightning is that zigzag line of light which appears to dart from cloud to cloud, or from the clouds to the earth. Its form is thought to be due to the character of the air through which the discharge passes, some portions offering greater resistance than others, and to the electricity always taking the easiest passage to the earth. Sometimes before a zigzag flash reaches the earth, it separates into a series of branches, and assumes a more definitely forked appearance. These branches are sometimes several thousand feet apart, and are frequently very dangerous.

Globular Lightning.—The discharge of very highly charged electrical clouds, instead of appearing as a flash, sometimes takes the globular form. A spherical ball of fire then is seen moving slowly from the sky towards the earth, in such a manner that the eye can easily trace it, as it pursues its downward course. It has been known to last as long as ten seconds. When it strikes the earth, sometimes it rebounds, at other times it splits up and disappears immediately. This is considered to be the thunderbolt that we hear and read of. It is a highly dangerous form of discharge, as it easily sets fire to buildings with which it comes into contact.

Thunder.

Thunder is the report which is heard when a discharge of atmospheric electricity takes place. If the discharge be near, it follows the flash almost instantaneously. It then produces most frequently a violent clash, known as a thunder-clap. When the discharge takes place at a distance from the spectator, an interval of time elapses after the flash is seen before the thunder is heard. This sometimes amounts to several seconds, and arises from the fact that sound does not travel so rapidly as light. The velocity of light over portions of the earth's surface within our range of vision is practically instantaneous ; but sound, at the ordinary temperature of the air, travels only 1,120 feet in a second. When, therefore, a certain number of seconds elapse between seeing the lightning and hearing the thunder, we know that the discharge has taken place at a distance equal to the distance travelled by sound per second multiplied by the number of seconds. Suppose, for example, 10 seconds were counted, the discharge would then have taken place 1,120 feet × 10, or 11,200 feet away. As this is a little more than two miles nearly we may say roughly that for every five seconds counted, one mile must be allowed. When the thunder comes from a distance it is heard as a rumbling sound, increasing and decreasing in loudness. This is due in part to the echoes or reflection of sound from the clouds, and at times to the flash producing centres of explosion, some of which are nearer to the observer than others, and the action of the sound-waves upon one another sometimes increasing, and at other times lessening, the intensity of the sound. Accidents from lightning are most common when the thunder follows close upon the flash.

The Return Shock.—Sometimes, however, accidents happen by what is termed *the return shock*, when the discharge has taken place at a distance from the injured person. This is due to the recombination of the two electricities of the human body after the person has been under the inductive influence of a highly electrified cloud. A body is sometimes partially insulated, but is in such a condition that the repelled electricity may pass gradually to, and the opposite kind be attracted as gradually from, the earth. The person thus becomes slowly but highly charged with the opposite kind of electricity to that of the cloud above. The electricity of the cloud is instantly discharged, and the person as quickly returns to the neutral condition by the opposite electricity leaving the body and passing to the earth, while the repelled electricity similar to that of the cloud returns. The shock produced by this return of the body to the neutral condition is sometimes so violent, that persons have been knocked down, and even killed by it ; but fatal accidents from this cause are not common. There is another form of the return shock, which arises from the person being perfectly insulated and under the inductive action of a highly electrified cloud. If the electricity of the cloud be positive, the upper portion of the body becomes negative, and the lower positive. When the cloud is discharged, these two electricities, which were only decomposed, recombine suddenly, and at times so violently that a sensible shock is felt.

Although the discharge of atmospheric electricity is sometimes dangerous to human beings, and destructive to buildings, protection may be afforded by the use of suitable rods, properly arranged, and attached to portions of the buildings which we desire to render secure. Such rods are named *Lightning Conductors.*

Lightning Conductors.

The lightning conductor consists of three parts :—

1. The rod.
2. The conductor.
3. The earth contact, or portion in the ground.

1. *The rod* is the part above the building, which should terminate in a very fine point. A thin platinum wire is

generally used for the top of it. The finer the point the more perfect is the action of the arrangement. Should the point of the rod be iron, it is gilded to prevent it from rusting.

2. *The conductor* is usually made of copper or iron. Copper is the best conducting substance, but iron improves after a time, whereas copper becomes more brittle. The best material for a conductor is a galvanised iron wire. Straps of copper are also used with good results. If an iron cylindrical conductor be used, $\frac{3}{5}$ in. in diameter will be sufficient; but if copper, $\frac{2}{5}$ in.

3. *The earth contact.*—This is a very important part of the lightning conductor, and unless it be carefully attended to, and the conductor led away into moist earth, the erecting of such an arrangement against a building will be a source of danger, rather than protection. The conductor should be taken for a little distance into the earth, and then turned at right angles to the building, and connected with the gas or water-pipes, or taken into a well or moist earth. If this cannot be secured, a narrow and deep pit should be dug, and the conductor led into it, and packed around with fresh charcoal. Charcoal should also surround it, as it extends from the building to the pit in which it terminates.

Use of Conductors.

The conductor acts on a highly electrified cloud in a similar way to a point, held in the hand, on the charged prime conductor of an electrical machine. It enables one kind of electricity to pass from the cloud to the earth, and the opposite kind to pass from the earth to the cloud; thus reducing the tension of the electricity of the cloud, and robbing it of its tendency to be dangerous in two ways. The distance rendered secure by a well-constructed lightning conductor is the area included within a circle, whose radius is the length of the height of the conductor from the ground. Large buildings should have more than one conductor attached to them to afford perfect security.

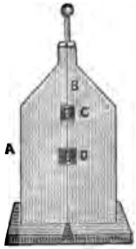
Experiments.—Show effect of a point held in the hand being presented to the prime conductor of an electrical machine highly charged.

Exhibit increase of tension, if point be removed, or covered with finger, by alteration of character of the spark. Test similarly, when a quadrant electrometer is attached to prime conductor. Notice rise and fall of pith-ball arising from changes in tension. Experiment also with a tissue-paper tassel, as in p. 55.

A very good experiment to illustrate this phase of the subject is shown in diagram fig. 94. Let A represent the gable end of a house, and B a lightning conductor attached to it; C and D are apertures in the end for the purpose of experiment, fitted with wooden squares, having wires running down the middle of the back, so that when they are in the position indicated by the dotted lines the conductor is continuous.

If now a highly charged Leyden jar be discharged through the conductor, the discharge passes without interruption through the wire, but if one of the squares be turned, so that the portion of wire attached to it may lie at right angles to the other parts, the passage of the electricity will be interrupted, and the square will be forced out of the aperture.

FIG. 94.



Apparatus to illustrate Electrical Discharge.

17. Suggestions as to Apparatus for Frictional Electricity.

Obtain a glass rod about 1 in. in diameter, and about 18 in. long. Close end, if possible, in a blowpipe flame; if not, stick a cork in it, leaving about ½ in. projecting.

Get a good stick of sealing-wax, sulphur, gutta-percha, and ebonite; also a thin sheet of indiarubber, a coarse sheet of brown paper, a sheet or two of foreign writing paper, and a piece of bottle indiarubber.

Make rubbers of silk and flannel by folding four sheets of either, and stitching them together. A sheet of flannel may lie inside the silk to act as padding.

Get two pieces of narrow white ribbon about 18 in. long, and some strips of thin gutta-percha about the same length.

If possible a catskin should be got, a fox's brush, and some gun cotton.

The following will be found useful :—a book of Dutch metal, a pennyworth of thin copper wire, a long lath, some string, hoops of cartridge paper, and an empty egg-shell.

A little shellac varnish should also be obtained for painting the glass rods, used as supports for insulating conductors.

This may be easily and cheaply made.

To make Shellac Varnish.

Pour the same weight of methylated spirit on shellac, and let it remain for 24 hours. Then dilute it with two or three times as much spirit. Strain it through flannel and keep it bottled. To varnish articles, heat them, so that they may be sensibly warm, but not too hot ; draw the brush regularly in the same direction ; don't disturb the varnish, but let it dry, or it will not lie smoothly.

To make an Electric Pendulum.

Fix glass rod coated with shellac varnish in wooden base. Fit brass cap to rod, and attach brass wire bent as in diagram, fig. 9, and terminating in a hook. Fasten pith-ball to a fibre of silk, and suspend it from the hook. The stand may be made by fastening a stick of sealing-wax to a tin plate. This can be done best by heating both the plate and the sealing-wax. A piece of bent wire may then be stuck into the end of the sealing-wax.

To make a Gold-Leaf Electroscope.

Get a glass jar, or large boiling flask. Fit a cork into it, and pass through the cork, insulated from it by a coating of gutta-percha or other good insulator, a brass rod. Solder a brass or copper disc, having a small hole near its edge, to the end of the rod. Attach also a strip of metal, say brass, at the other end of the rod, and at right angles to it. Stick with gum or paste two equal strips of gold leaf or Dutch metal. They should be about $\frac{3}{4}$ in. wide, and 2 in. long.

To make a Proof Plane.

Cut out two pieces of thin cardboard, one circular, diameter $1\frac{1}{2}$ in., and the other oblong 3 in. by 2 in.; round off corners of latter, cover each smoothly on both sides with tin-foil, and fasten separately to a strip of glass about 9 in. long and $\frac{1}{2}$ in. wide; coat glass strips with shellac varnish. Pieces of gilt or silvered paper may be used instead, or discs of thin metal.

To make an Electrophorus.

Obtain circular base of ebonite, gutta-percha, or resin, or even coarse brown paper; let it have a diameter of about 9 in. To the centre of a disc of tin or thin brass, 7 in. in diameter, fasten a sealing-wax, gutta-percha, or glass handle, about 6 in. long. Should the handle be glass, a coating of shellac varnish will be necessary.

Conductors.

The various shaped conductors may be made of wood, and coated with tin-foil. This must be done smoothly, so as to avoid edges or points, otherwise the electricity will rapidly escape. They may be supported on glass rods coated with shellac varnish.

Such bodies as apples, turnips, potatoes, and carrots, if smooth and warmed, may be used as conductors, and can be supported by a needle projecting from a stick of sealing-wax. The sealing-wax should be fastened to a tin disc to support it.

To form an Insulating Stool.

An ordinary drawing-board well warmed, and placed on four glass tumblers, will serve for this. It is advisable to coat the tumblers with shellac varnish to secure more perfect insulation, if not coated they should be well warmed.

To make a Faraday's Butterfly Net.

Form a circle with fairly thick wire; the diameter of the circle should be about 4 in. Let the two ends of the wire, after the circle is completed, be secured with shellac in a piece of glass tubing, 9 in. long and ¼ in. in diameter. Make a conical gauze bag, with base 4 in. and length 9 in., and attach it to the circle. Fasten two silk strings, each about 18 in. long, one to the inside and the other to the outside of the apex of the cone.

To make a Fulminating Pane, or Franklin's Plate.

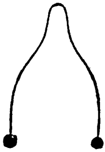
Coat both sides of a sheet of glass 12 in. by 9 in., with equal-sized sheets of tin-foil, so that they may cover one another exactly. The foil should be 8 in. by 5 in., so as to allow a 2 in. border of glass all round the foil. Coat the glass border with shellac varnish.

To make a Leyden Jar.

Paste tin-foil inside and outside of a wide-mouthed, thin glass bottle, to about 2 in. from the top. Fit large cork or wooden stopper into the mouth of the jar. Pass thick brass wire through centre of stopper. Attach a knob to one end of wire, and a piece of chain or wire to the other. The chain or wire must be in contact with the inner coating of the jar.

To make a Discharging Rod.

FIG. 95.



Discharging rod.

Get a good-sized test tube. Bend a piece of copper wire ⅛ in. thick into the shape represented in diagram, fig. 95. Solder two leaden bullets to the ends. Secure bent portion in the test tube with shellac.

To make a Leyden Jar with movable coatings.

Obtain a smooth glass tumbler, have two tin cups fitted to the outside and inside. A thick (⅛ in.) brass wire should be attached to the inner cup. The upper portion of this should be bent into a hook, and terminate in a knob.

Red lead and flowers of sulphur should be procured to illustrate Lichtenberg's figures.

A cylinder or plate machine should be added to the apparatus if possible.

18. Brief History of the development of Frictional Electricity.

First reference to it.—Thales, one of the Greek philosophers, noticed that, when *amber* was rubbed, it attracted light bodies; B.C. 600.

Real start of the Science.—This is due to the investigations of Dr. Gilbert, who was a physician to Queen Elizabeth. He proved that various other substances, when they were rubbed, showed like properties to amber; A.D. 1600.

The next important experimenter was Robert Boyle, A.D. 1675, who first noticed *the light* given out by a diamond when it was rubbed in the dark.

First Electrical Machine.—The first electrical machine is due to Otto von Guericke, who lived at the same time as Boyle. This consisted of a ball of sulphur turned by a handle; the dry hand, pressing against the ball while it was turning, served as the rubber.

Subsequent Machines.—Hawksbee substituted a glass globe for the sulphur globe, A.D. 1709. Boze, a German philosopher of Wittenberg, A.D. 1741, added to Hawksbee's machine the prime conductor, which consisted of a tin tube, either fixed on a resin support, or hung by a silk thread. Winkler, a professor at Leipsic, was the first to use a fixed cushion as the rubber for the glass globe. This globe soon gave place to the glass cylinder, which was introduced by Gordon.

The Plate Machine, according to Professor Tyndall, is due to Planta, A.D. 1760; but Ganot and Deschanel attribute it to Ramsden, A.D. 1768.

Conduction and Insulation.—These were the results of the investigations of Stephen Gray, A.D. 1729. He also noticed the electric brush, snappings, and sparks, and experimented on induction.

Vitreous and Resinous Electricity.—These two kinds of electricity were first announced by Du Fay, about A.D. 1733, and his name became attached to what was afterwards known as *the two fluid theory.*

Positive and Negative.—Franklin, A.D. 1747, substituted the terms 'positive' and 'negative' for 'vitreous' and 'resinous' in connection with his *one fluid theory.*

Symmer's Theory.—Symmer adapted Du Fay's theory to the positive and negative idea introduced by Franklin; and henceforth the two fluid theory became more immediately connected with the name of Symmer.

The Leyden Jar.—This jar has received its name from its being discovered in a rough form by Cunæus, a rich burgess of Leyden, A.D. 1746. Tyndall remarks, 'It was first announced in a letter addressed on the 4th of November, 1745, to Dr. Lierberkühn, of Berlin, by Kleist, a clergyman of Cammin in Pomerania.' Its present form is due to the investigations of Dr. Bevis, and Dr. Watson, but chiefly the latter.

The Unit Jar.—The two chief bear the name of Harris and Lane.

Electrical Laws.—These were established by Coulomb by means of experiments with the Torsion Balance, A.D. 1787.

The Electrophorus and Condensing Electroscope.—Both these apparatus bear the name of Volta. The former was invented A.D. 1775, and the later A.D. 1782.

The Electroscope.—The Gold-Leaf Electroscope is due to Bennett, and is sometimes named Bennett's electroscope.

Atmospheric Electricity.—Franklin was the first and greatest investigator in atmospheric electricity. He was followed by D'Alibard, and Richmann, of St. Petersburg.

The latter met his death from lightning, while experimenting with an insulated rod, A.D. 1753.

Lightning Conductors.—These were first introduced by Franklin, A.D. 1749, and after much discussion were adopted. A lightning conductor was first attached to St. Paul's Cathedral. Another prominent name connected with lightning conductors, particularly those of ships, is that of Sir Snow Harris, of Plymouth. Since then various eminent men have investigated different portions of this important science, and have aided its development by their studies and experiments. Foremost amongst a long array stand the names of Sir Humphry Davy, Faraday, Tyndall, Guthrie, and Sir William Thompson.

REESE LIBRARY UNIVERSITY CALIFORNIA

SCIENCE AND ART DEPARTMENT QUESTIONS.
FRICTIONAL ELECTRICITY.

ELEMENTARY STAGE.

1867.

1. We often hear of an 'electric fluid.' What are your notions regarding it? P. 9.
2. If asked to show some of the elementary effects of electricity, how would you do it? P. 3.
3. How is electricity stored in the Leyden jar? Pp. 68-73.
4. We hear of frictional electricity, and of voltaic electricity. What is the difference between them? Describe the ways in which both of them may be obtained. Partly p. 3.
5. What are lightning-conductors? and how do they act in averting danger from lightning? Pp. 119–120.

1868.

1. What is meant by the term insulated? I bring a glass rod which has been rubbed with silk near an insulated brass sphere; what is the condition of the sphere while the glass is near it? What occurs when the glass is removed? Pp. 32-33.
2. If you take an insulator in your hand and rub it properly you electrify it; if you do the same with a conductor you obtain no signs of electricity; what is the reason? Bodies were formerly divided into electrics and non-electrics; why? Pp. 26–27.
3. Explain in accordance with the theory of electric fluids the attraction of light bodies by an electrified glass rod. Pp. 36–37.
4. Describe and explain the original experiment which led to the discovery of the Leyden jar. Pp. 66–67.
5. Describe some one form of electric machine, and explain its use. Pp. 46–47.

1869.

1. An electrified body is brought near a scrap of paper or of gold leaf resting on a metallic surface; what happens to the scrap, and what is its exact electrical condition when it is attracted? Sup-

posing it to rest on a surface of shellac, what would be its condition when attracted by the electrified body?

2. Describe the gold-leaf electroscope, and state the principle of its action. Pp. 16–18.
3. I grind sulphur in a mortar and thus electrify it. I place some of the electrified powder on the plate of a gold-leaf electroscope; the leaves diverge; why? since the sulphur is an insulator, and does not part with its electricity. I remove the powder by means of an insulator; what will occur, and why will it occur?
4. I place a sheet of vulcanised indiarubber on a sheet of tinfoil, and a second sheet of tinfoil upon the rubber. I connect the lower sheet with the earth, and the upper one with the conductor of an electrical machine; what occurs when the machine is set in action? P. 64.

1870.

1. If you rub a stick of sealing-wax held in the hand with flannel it becomes electrified; if you rub a rod of brass you do not electrify it. What is the reason of this difference? Pp. 26–27.
2. When you think of an electrified body, in what way do you picture it to your mind? Pp. 84–86.
3. Give a sketch of the theory of electric fluids. Pp. 9–10.
4. When you rub a stick of sealing-wax with flannel what is the state of the rubber? When you rub a stick of glass with silk what is the state of the rubber? Pp. 22–23.
5. How do you suppose thunder and lightning to be produced? Pp. 115–116.

1871.

1. I wish you to show me a few simple electrical effects; how will you do it? Pp. 3–4.
2. I wish you to prove that like electricities repel each other, and that unlike electricities attract each other; but you are first to state what image you have in your mind when you speak of electricity at all. Pp. 23–24.
3. Do you know what electrical induction is? If so, describe an experiment which shall illustrate it. Pp. 24–37.
4. A Leyden jar is hung up in the air by a silk string; the knob of the jar is connected with an electric machine, and its outer coating is connected by a wire with a large gas-pipe. What occurs in this outer wire when the machine is worked? and why does it occur? P. 68.
5. Why do I employ a silk string to suspend the jar in the last experiment? What would happen supposing the string to be ordinary twine? Let your answer be as clear and as complete possible. Pp. 68–70.

1872.

1. If upon a warm board a dry sheet of paper be rubbed with indiarubber it is electrified. How is this proved? P. 3.
2. Show by a simple experiment that the electricity developed on resin by the friction of flannel is different from that developed on glass by the friction of silk. Pp. 12–14.
3. Describe Franklin's Plate, and explain its action. Pp. 64–65.
4. A strip of paper rubbed with indiarubber is brought near to a glass rod which has been rubbed with silk: what follows? Deduce from the experiment the quality of the electricity upon the paper. P. 14.
5. Explain fully what takes place when light bodies are attracted by a stick of sealing-wax rubbed with flannel. Pp. 4, 37.

1873.

1. I hold a dry glass rod, which has been rubbed with silk, near a brass ball, which is supported on a dry glass stand; what is the state of the ball? Supposing the stand which holds the brass ball to be moist instead of dry; what will occur? Pp. 32–33.
2. Two strings are given to you, and you are required to test whether they insulate or conduct electricity; how will you do it? Pp. 28–29.
3. Two brass balls supported on glass stands are united by a chain; a stick of sealing-wax rubbed by flannel is brought near one of the balls; what is the condition of the other? Pp. 40–41.
4. You touch the ball furthest from the sealing-wax, remove your hand, and then remove the sealing-wax; what is now the electrical condition of the two balls and the chain? You must state what occurs at each step of the process. P. 33.
5. You are required to charge and discharge a Leyden jar; how will you do it? Pp. 67–72.
6. There are two kinds of electricity, called positive and negative. You rub sealing-wax with flannel; are both electricities excited, or are they not? If both, where? If only one, where? P. 22.

1874.

1. A collodion balloon simply stroked with the hand becomes negatively electrified. Supposing you were asked to prove the truth of this statement, how would you proceed? P. 14.
2. An egg-shell is placed on a table, and a glass rod which has been rubbed with silk is brought near the shell; the shell rolls after the rod. Describe the condition of the rod and the shell during the motion of the latter.
3. You are required to prove by experiment the electrical law that

bodies similarly electrified repel; and that bodies dissimilarly electrified attract each other: how will you do it? Pp. 23–24.

4. Describe the Leyden jar and the mode of charging it. Pp. 67–69.
5. Describe the electrophorus and the mode of charging it. Pp. 42–44.

1875.

1. From what is the word electricity derived? Describe the substance with which the first electrical effects were observed, and describe also the mode of exciting it. P. 1.
2. You are required to electrify strongly a glass tube: how will you do it? You are required to electrify strongly a tube of gutta-percha: how will you do it? Pp. 4, 14.
3. What is the action of two electrified glass tubes upon each other? What is the action of two electrified gutta-percha tubes upon each other? What is the action of an electrified glass tube upon an electrified tube of gutta-percha? P. 4.
4. I stick a bit of sealing-wax against a penny or a halfcrown; and I whisk a bit of vulcanised indiarubber with a fox's brush. Holding the sealing-wax as a handle, I lay the penny or halfcrown flat on the indiarubber. What is the condition of the coin? I touch the coin, what occurs? I lift it by the handle, what is its condition? Pp. 42–44.
5. You are required to explain, in accordance with the theory of electric fluids, how light bodies are attracted by a glass rod positively electrified, and by a gutta-percha tube negatively electrified?

1876.

1. What is meant by the terms *conduction* and *insulation* as applied to frictional electricity? Describe an experiment which shall illustrate the properties of metal wire, common twine, and a silk string as regards conduction and insulation. Pp. 25–30.
2. A sheet of hot paper is placed on a board, and indiarubber is passed briskly over it. Two strips are cut from the paper and held up close and parallel to each other. How will they act upon each other? A glass rod rubbed with silk repels both the strips; what is the inference? Pp. 7–8.
3. Describe and explain the action of the common gold-leaf electroscope. Pp. 16–20.
4. An apple held in the hand and struck with a fox's brush shows no signs of electrical action; suspended by a silk string and struck with the brush it becomes electrified, attracting light bodies, and causing the leaves of the electroscope to diverge. Explain these results. Pp. 26–27. *The apple is a conductor like brass rod.*
5. A stout stick of sealing-wax is stuck upright to a piece of wood acting as a base; into the wax at the top is inserted a needle, and on to the needle is fixed an apple. Near to the apple, but not into contact with it, is brought a rod of glass which has been rubbed by silk. What is the condition of the apple while the

rod remains near it? What occurs when the apple is touched for a moment? What finally occurs when the rubbed glass is withdrawn? P. 36.

1877.

1. A lath, six feet long, is supported at its centre on a dry glass tumbler. Below one end of the lath, and at a distance of some inches from it, are placed some scraps of gold leaf or other light bodies. A glass rod electrified by friction is brought over the other end of the lath without touching it. The fragments of gold leaf are immediately attracted. How is this attraction produced?
2. You are required to give an experimental proof of the law that bodies oppositely electrified attract each other, and bodies similarly electrified repel each other. Tell me the substances you would choose, and the manner in which you would use them to obtain the required result. Pp. 12–14.
3. A thunder-cloud charged positively comes over a pointed lightning-conductor. The cloud generally loses its charge of electricity by the action of the conductor. How is this accomplished? P. 120.
4. You are required to make a small Leyden jar: how will you proceed? You are required to charge the jar when made: how will you do it? Pp. 67–70.
5. You are required to explain fully what occurs during the charging and discharging of your Leyden jar. Pp. 67–72.

1878.

1. Give a clear definition of the terms electric *conduction* and electric *induction.* Pp. 28, 29, 34.
2. Supposing you were required to develop induced electricity and to prove its existence, how would you do it? P. 40.
3. Supposing you were required to test the quality of the electricity with which an insulator is charged, how would you do it? P. 18.
4. What occurs when you whisk the resinous plate of an electrophorus with a fox's brush? The plate being excited, how would you obtain the spark of the electrophorus? P. 43.
5. Describe an experiment which shall illustrate the action of the electrical condenser. Pp. 60–61.

1879.

1. If you rub together a stick of sealing-wax and a piece of flannel, and then put them both on an electroscope, the leaves do not move. What happens to the electroscope if you remove (1) the flannel, (2) the sealing-wax? What would be the effect in each case of bringing near the electroscope a glass rod that had been rubbed with silk? P. 22.
2. How would you prove that a brass tube is negatively electrified when struck with flannel? Pp. 8 or 18.

3. Describe fully how you could charge a Leyden jar from the positive conductor of an electrical machine, so as to get at will either a positive or a negative charge on the inner coating. Pp. 67–69.
4. An electrified metal ball hung by a silk thread is allowed in one case to touch the inside of an insulated metal jar, in another case to touch the outside of the jar. What would be the result of afterwards connecting (1) the ball, and (2) the jar, with an electroscope?
5. An insulated electrified conductor can be discharged by bringing near it the point of a sharp needle held in the hand. Explain this. Pp. 95–96.

1880.

1. You have several rods of unknown materials. Describe exactly experiments which would enable you to distinguish those of them which are conductors of electricity from those which are non-conductors. P. 28.
2. Could an electrical machine be made to act if it had a metal plate instead of a glass plate? If not, why not? If it could, show how. P. 52.
3. Describe experiments which show that the terms *vitreous* electricity and *resinous* electricity are inappropriate. Pp. 7–8.
4. Show why it is necessary, in order to obtain a succession of sparks from the prime conductor of an electrical machine, that the rubber should be connected with the ground. P. 48.
5. One person holds a charged Leyden jar in his hand by its outer coating, and another holds similarly an uncharged jar. What happens when the knobs of the two jars are brought together?

1881.

1. If two insulated bodies A and B are rubbed together and A becomes positively electrified, what is the electrical condition of B? (1) as to the kind of electrification, (2) as to the amount of its electrification as compared with that of A. Pp. 10–11.
2. If you have a penny fastened to the end of a stick of sealing-wax, how could you give it a negative charge by help of a positively charged glass rod? P. 36.
3. A pewter pot is insulated and electrified; if you touch it at different parts with a penny stuck to the end of a rod of sealing-wax, what part of the pot will give the greatest quantity of electricity to the penny? P. 86.
4. How is it that you do not get a shock on touching the knob of a Leyden jar which stands on a cake of resin? P. 72. *You do not connect the outer and inner coatings.*
5. If you want to find out whether a body is electrified by seeing how it acts on an electrified pith-ball hung by a silk thread, why is it a surer test that the body is electrified if it repels the pith-ball than if it attracts it? P. 13.

1882.

1. A stick of sealing-wax is rubbed with dry flannel, and held over
pith-ball lying on a table. The ball rises to the sealing-wax an
then falls again. Why does it rise, and why does it fall? Pp. 36–3
2. When a piece of sealing-wax and a piece of dry flannel are rubbe
together, one becomes positively electrified and the other neg
tively electrified. When a piece of dry paper and a piece
indiarubber are rubbed together one becomes positively electrifie
and the other negatively electrified. How could you find o
which of the four things, sealing-wax, flannel, paper, indiarubbe
are in the same electrical state? P. 21.
3. Describe a Leyden jar and the method of charging it. Pp. 67–69.
4. A piece of dry brown paper, laid on a warm metal tray, is rubbe
with catskin. The tray is then placed on a dry glass tumbler ar
the brown paper is removed. Explain how it is that you can no
get a spark on bringing your knuckle near the tray. Pp. 42–4
5. Arrange the following substances in the order of their conductir
powers for electricity, putting the name of the best conduct
first: air, copper, glass, iron, sea-water, shellac, water (pure
wood. Pp. 24–25.

1883.

1. A piece of brass tube held in the hand and struck with catskin sho
no electricity when it is made to touch an electroscope. Ho
would you prove experimentally that it was really electrifie
when so struck? Pp. 26–27.
2. How is it that in damp weather an ordinary plate machine will n
work well? Pp. 4, 49.
3. In the common plate or cylinder electrical machine the conductor
of rounded shape at all parts except where it comes nearest
the plate or cylinder, but here it is provided with sharp projecti
points. What reason is there for this arrangement? Pp. 48, 9
4. A little pith-ball rests on a brass plate provided with a glass handl
The two are placed on a cake of resin, which has been rubb
with a catskin. When the plate is touched by the finger, a
then lifted by the handle, the pith-ball jumps off the plate; wh
Pp. 43–44.
5. A deep metal pot, positively electrified, stands on a glass stem.
metal ball, hung by a silk thread, is put in contact with a go
leaf electroscope after being made to touch—
    (*a*) first the *inside*, and then the *outside* of the pot; or
    (*b*) first the *outside*, then the *inside* of the pot.

    State and explain the effect on the electroscope in each case. P
90–91.

1884.

1. If you have a positively charged brass plate and a piece of gilt pa
fastened to the end of a dry glass rod, how could you charge
gilt paper with negative electricity? P. 36.

The prime conductor of an electrical machine has a long brass rod projecting from it; from the end of a rod a pith-ball hangs by a damp cotton thread, and a pin is driven into the pith-ball up to its head, so that the point projects on the other side. How and why does the ball move when the machine is turned?

Three insulated metal balls, A, B, and C, are placed in a line, A and B in contact, C a little way off. C is positively electrified, and then A and B are separated. What are now the electrical states of A and B? P. 41.

You have an electrical machine standing on a table with a glass top, and you have no means of connecting it electrically with the earth. What would you do in order to charge a Leyden jar by the machine? P. 53.

Under what circumstances can you get a charge on a metal ball hanging by a silk thread by touching therewith the *inside* of a metal jar?

1885.

Two pith-balls suspended, one by a damp cotton thread, the other by a dry silk thread, are each of them touched by the knob of a charged Leyden jar, which is held in the hand by its outer coating. Will there be any difference between the behaviour of the two balls? If so, what difference? and why?

Two pith-balls hang side by side by two damp cotton threads. State and explain what happens when an excited glass rod is brought gradually near the two balls from below.

Say exactly what you must do in order to get a succession of sparks from an electrophorus. P. 44.

A brass rod is supported horizontally by a dry glass stem, and a large, strongly electrified metal ball is brought near one end of the rod (but not near enough for a spark to pass). The rod is then touched for an instant by the end of an earth-connected wire, and afterwards the ball is removed. Will it make any difference in the final electrical state of the brass rod, whether the wire touches it at the end nearest the ball, at the end farthest from the ball, or at the middle? Give reasons for your answer. Pp. 33, 34, 36.

On touching the knob of a charged Leyden jar standing on the floor, or on a common table, you get an electric shock; but if either you or the jar stand on a dry cake of resin, you do not get a shock on touching the knob. Explain this.

You break the conducting connection between the outer and inner coatings, and thus prevent the interchange of the two electricities, and the discharge of the jar.

PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
LONDON

UNIVERSITY OF CALIFORNIA LIBRARY
BERKELEY

Return to desk from which borrowed.
This book is DUE on the last date stamped below.

29Jan'49RW

Wasson
March 1, 1949

MAR 1 1949

SEP 21 1993

AUTO DISC CIRC DEC 15 '93

LD 21-100m-9,'48(B399s16)476

YA 01167

U. C. BERKELEY LIBRARIES

C041445692

34666

QC 518
T4

Google